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NOTE.

THE authors of the several papers contained in this volume are themselves accountable for all the statements and reasonings which they have offered. In these particulars the Society must not be considered as in any way responsible.

I.—Empirical Formulæ for the Relation between the Temperature and Pressure of Saturated Vapour.

By A. ADAMSON, M.Sc.Tech., A.R.C.S., Lond.,

THE fact that the pressure of a saturated vapour depends only upon the temperature and the nature of the substance has encouraged many attempts to obtain a formula connecting the pressure p and the temperature t. Several simple formulæ have been suggested which apply accurately only over a small range of temperature, but attempts to cover a large range have generally introduced formulæ giving p as the sum of several separate functions of t, with constants either undetermined, or which, when given, differ considerably for different substances and are difficult to memorise. Moreover, such formulæ cannot be used to determine values of t for given values of p.

The following treatment gives empirical formulæ which are easy to manipulate and memorise, and which give p from t, or t from p with great accuracy over large ranges.

I.—*Given the pressure of saturated water vapour at* 100° *C. and at* 90° *C. to find the pressure at temperatures differing by* 10° *over the whole range from* − 10° *C. to* 370° *C.*

Let the pressure of saturated water vapour at t° C. $(t - 10)$° C. and $(t + 10)$° C. be p, p_1 and p_2 respectively, and let

$$\frac{\log p - \log p_1}{\log p_2 - \log p} = r.$$

Then using the experimental values given by Holborn and Henning in Landolt and Bornstein's tables, p. 1316 (1923), it will be found that the value of r decreases from 1·090 at $-10°$ C. to 1·027 at 370° C.

If the values of r are plotted against values of t it will be found that the points obtained lie close to a parabola the equation to which is

$$r = 1{\cdot}1144 - \frac{1}{1000}\sqrt{18{\cdot}6t + 775}.$$

Using this formula to find r, and assuming that when $t = 100°$, $p = 760$ mm. and $p_1 = 525{\cdot}76$ mm., we may find, step by step, the whole series of values of p.

The values obtained differ from Holborn and Henning's results by less than 0·05 per cent. from 10° C. to 100° C., and by less than 0·5 per cent. up to 350° C.

II.—*To obtain intermediate values of* p *or* t *for water.*

If experimental values of $\log p$ be plotted against t, the form of the graph suggests a rectangular hyperbola the equation to which would be

$$(a - \log p)\ (c + t) = b.$$

No constant values given to a, b and c will agree with the experimental values over the whole range, but the formula may be employed to interpolate for each range of 20°, the values of a, b and c being determined for each range. The value of c for each range of $t - 10$ to $t + 10$ is given by the formula,

$$c + t = 10 \times \frac{r+1}{r-1} = \frac{20}{r-1} + 10,$$

$$\text{since } r = \frac{\log p - \log p_1}{\log p_2 - \log p} = \frac{\dfrac{b}{c+t-10} - \dfrac{b}{c+t}}{\dfrac{b}{c+t} - \dfrac{b}{c+t+10}} = \frac{c+t+10}{c+t-10}.$$

III.—*Application of Dühring's law to determine approximately the pressure of saturated vapour of any substance, at any temperature, given the temperatures corresponding to two specified pressures, and the series of values for water vapour as obtained in (I.).*

Dühring has shown that as we pass from two temperatures of equal vapour pressure for two substances to two other temperatures of equal pressure, the changes of temperature are approximately proportional, or, in other words, if the temperatures of the boiling-point of one liquid be plotted against the temperatures of the boiling-point of another liquid at the same pressure the graph obtained is approximately a straight line.

Assume that this law holds good for water and for another substance and determine, by experiment or otherwise, the temperatures θ and $\theta + d$ at which the maximum vapour pressure of the other substance is the same as that of water at any pair of temperatures t and $t + 10$ in the series referred to in (I.). Then the series of pressures obtained for water vapour at temperatures differing from t by increments of 10 will also be the series of pressures for the vapour of the other substance at temperatures differing from θ by increments of d.

Intermediate values of p for each range of temperature of $2d$ between $\theta + d$ and $\theta - d$ may be obtained by using the same formula $(a - \log p)\ (c + \theta) = b$ with appropriate values of a, b and c.

In this case $c + \theta = d \times \dfrac{r + 1}{r - 1} = \dfrac{2d}{r - 1} + d.$

IV.—*Method to obtain approximately and directly the value of* p *given* t, *or of* t *given* p, *for water, or any other vapour obeying approximately Dühring's law and the law* $(\mathrm{a} - \log \mathrm{p})(\mathrm{c} + \mathrm{t}) = \mathrm{b}$, *given two pairs of values of* p *and* t.

Let t_1, θ_1 be the temperatures for two such substances corresponding to a saturated vapour pressure p_1, and let t_2, θ_2, be the temperatures for the same substances corresponding to a pressure p_2.

Then by Dühring's law $\dfrac{t_1 - t_2}{\theta_1 - \theta_2} = \text{constant} = k,$

and since $t_1 - t_2 = \dfrac{b}{a - \log p_1} - c - \dfrac{b}{a - \log p_2} + c,$

and $\theta_1 - \theta_2 = \dfrac{b'}{a' - \log p_1} - c' - \dfrac{b'}{a' - \log p_2} + c',$

therefore $$k = \frac{b\left[\dfrac{1}{a - \log p_1} - \dfrac{1}{a - \log p_2}\right]}{b'\left[\dfrac{1}{a' - \log p_1} - \dfrac{1}{a' - \log p_2}\right]}.$$

Since this is true for all values of p_1 and p_2 the constant a' must be equal to a. In other words, the constant a would have the same value for all substances if the vapour pressure obeyed the two laws. Actually the value of a for water vapour over small ranges when p is expressed in mm. of mercury, decreases from 8·27 at 0° C. to 7·93 at 140° C., and then increases to 8·39 at 300° C. Thus for approximate results we may take $a = 8$ so that the formula for any substance becomes $(8 - \log p)\ (c + t) = b$. In this formula, and in all that follow, logarithms are taken to the base 10.

Applying this formula to the experimental values given in reliable tables for different substances, we find a close agreement over moderate ranges of temperature, and in some cases remarkably close agreement over the full range given in the tables. The values obtained for the constants b and c for a few substances are given below. The amount of the possible error in calculating t from p is indicated by the variation of c.

Substance.	Temperature Range.	*b*.	*c*.
Water . .	− 10° C. to + 35° C.	1700	231·64 ± 0·03
,, . .	120° C. to 260° C.	1700	232·22 ± 0·04
,, . .	− 10° C. to 300° C.	1695	231 ± 0·23
Ethyl alcohol	0° C. to 240° C.	1551	224$\frac{2}{3}$ ± $\frac{2}{3}$
Methyl alcohol	0° C. to 236° C.	1533	234$\frac{2}{3}$ ± $\frac{1}{3}$
Ethyl ether .	10° C. to 60° C.	1700	297·3 ± 0·3
,, ,, .	50° C. to 190° C.	1900	339·4 ± 1·2
Naphthaline .	200° C. to 300° C.	2750	319 ± 0·6
Mercury .	100° C. to 420° C.	3300	287 ± 1·3

An interesting application of the formula,

$$(8 - \log p)(t + 231{\cdot}64) = 1700,$$

for water between $-10°$ C. and $+35°$ C. is to determine the percentage relative humidity (H) of the atmosphere in terms of the temperature ($t°$ C.) and the dew point ($d°$ C.). If p_t and p_d are the saturation pressures of water vapour at $t°$ C. and $d°$ C. respectively,

$$\begin{aligned} H &= 100 \times \frac{p_d}{p_t} \\ \log_{10}H &= 2 - (\log p_t - \log p_d) \\ &= 2 - \frac{1700}{d + 231{\cdot}64} + \frac{1700}{t + 231{\cdot}64} \\ &= 2 - \frac{t - d}{31{\cdot}56 + 0{\cdot}136(t + d) + 0{\cdot}0006td} \end{aligned}$$

or approximately,

$$\log_{10}H = 2 - \frac{t - d}{31{\cdot}6 + 0{\cdot}14(t + d)}.$$

With this approximate formula, the maximum error in the percentage humidity is not more than 0·13 for the range of temperatures from 0° C. to 35° C.

It appears from the formula that for a constant relative humidity the dew point is a linear function of the atmospheric temperature. Direct determinations of the dew point at different temperatures from Holborn and Henning's tables of vapour pressures, show that this law is very approximately true, especially at high percentage humidities.

V.—*Graphical Methods.*

We may now modify Dühring's straight line graph so as to obtain corresponding values of p and t for any substance approximately, being given two pairs of values.

Plot known experimental values of t against corresponding values of $\dfrac{1}{8 - \log p}$.

Then, since $c + t = b \times \dfrac{1}{8 - \log p}$, the graph obtained is approximately a straight line, which is fixed by two pairs of

values. Even if the best value of a for a liquid is not exactly 8, the graph will be approximately straight, especially if the range is small.

In order to avoid the calculation of the values of $\dfrac{1}{8 - \log p}$, the following method may be employed. On a straight line AB make an even scale on which to mark off values of log p. On any parallel line CD mark off a scale of temperatures for corresponding values of t.

Through the point E corresponding to log $p = 8$, draw EF perpendicular to AB meeting CD at F. Draw any straight

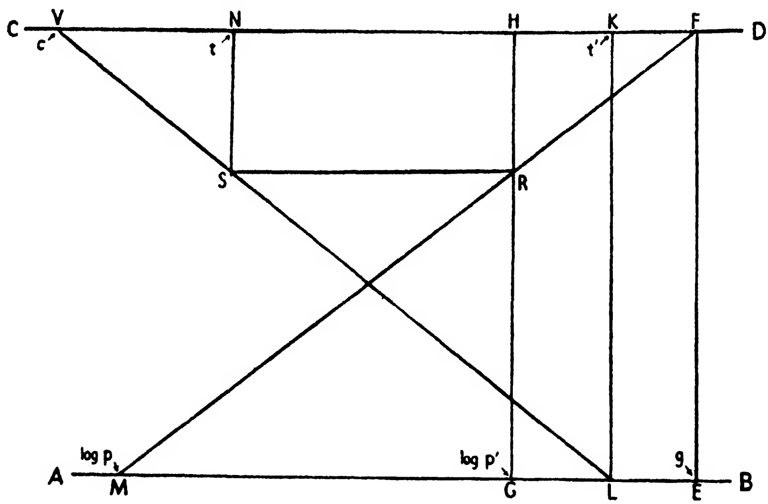


FIG. 1.

line GH perpendicular to AB. Let G be the point on the scale for log p^1, and let K be the point for the corresponding temperature t^1. Draw KL perpendicular to AB, to meet AB at L.

Let M and N be the scale points corresponding to any pair of values log p and t. Join MF intersecting GH at R. Through R and N draw the co-ordinates RS, NS. Join LS and produce LS to meet CD at V. Let the temperature scale reading at V be $-c$. Then

$$\frac{c+t}{c+t^1} = \frac{VN}{VK} = \frac{NS}{KL} = \frac{HR}{HG} = \frac{RF}{MF} = \frac{GE}{ME} = \frac{8 - \log p^1}{8 - \log p}.$$

Therefore $(8 - \log p)(c + t) = (8 - \log p^1)(c + t^1)$
$= \text{a constant for all values of } p \text{ and } t.$

Hence, if the formula $(8 - \log p)\ (c + t) = b$, b and c being constant, holds good for any saturated vapour, the graph for S will be a straight line such as LV.

In practice the graph would be fixed by determining the two positions of S corresponding to any two pairs of values of p and t.

VI.—*Accurate determinations of* p *from* t, *or* t *from* p.

In general the results obtained from the formula

$$(8 - \log p)\ (c + t) = b$$

are only approximately true, since b and c are not exactly constant and 8 is only an approximation to the exact number. Accurate results may generally be obtained for any substance by retaining the value 8, determining b approximately by plotting as many known values as possible, and drawing the mean straight line, and then calculating the value of c for each pair of known values of p and t. In general the value of c, which is now regarded as a function of t, will only vary slightly throughout the whole range of values of t. Values of c may be plotted against t and the graph used to obtain appropriate values for any temperature which, when substituted in the equation $\log p = 8 - \dfrac{b}{c + t}$, give values of p closely in agreement with experimental results.

In order to determine t given p, a mean value of c may be used to find t approximately, then c may be found and substituted in the formula to find t exactly.

In some cases the form of the graph c against t, suggests some curve whose equation can be found. For example, for mercury the points of the graph for temperatures between 100° C. and 450° C. lie close to the parabola $c = 288{\cdot}36 - \dfrac{(t - 270)^2}{11000}$ when the value of b is 3300. For ethyl

alcohol when $b = 1551$ the value of c follows approximately the sine curve $c = 224 + \frac{2}{3}\left[1 + \sin\frac{9(t - 80)^\circ}{5}\right]$.

For water if b be taken as 1700, the graph for c follows a curve which may conveniently be divided into three sections for three ranges of temperature.

From $-10°$ C. to $+70°$ C. $c = 231{\cdot}625 + \dfrac{(t - 12)^2}{12000}$.

From 70° C. to 200° C. $c = 232{\cdot}263 - \dfrac{(t - 160)^2}{20000}$.

And from 200° C. to 370° C. $c = 232{\cdot}19 + \dfrac{(t \sim 228)^3}{640000}$.

When these values of b and c are substituted in the formula $\log p = 8 - \dfrac{b}{c + t}$, the order of accuracy for the values of p for these three substances is as follows:—

For mercury between 100° C. and 420° C. the departure from experimental values of p is less than 0·4 per cent., the pressure ranging from 0·28 mm. to 2120 mm.

For ethyl alcohol between 10° C. and 240° C. for pressures varying from 24 mm. to 45,500 mm., the departure is less than 0·5 per cent.

For water, provided that at temperatures near to 70° C. and 200° C. (where two ranges meet), the mean value of c is taken, the values of p are less than 0·05 per cent. different from Holborn and Henning's results for temperatures from $-10°$ C. when the pressure is 2·143 mm. to 320° C., when the pressure is 84,700 mm. For temperatures up to the critical temperature 374° C., the difference from their results is less than about 0·5 per cent.

When compared with values of p given in pounds per square inch for every 10° C. as the results of experiments by Holborn and Henning, by Keyes and Smith, and by G. S. Callendar, the values obtained by the above formulæ for water vapour are never more than 0·4 pounds per square inch different from one or other of the sets of experimental values throughout the whole range of temperatures to 370°, except at 340° C., where the difference is 0·7 pounds per square inch,

the value of the pressure at this temperature being 2120 pounds per square inch. The percentage variation from one or other of the sets is less than 0·05.

The formula $(8 - \log p)(c + t) = b$ may be altered to give p in other units than mm. of mercury, by replacing 8 by the appropriate constant number, for example, $8 - \log 760$ to give p in atmospheres, and $8 - \log 760 + \log 14{\cdot}696$ to give p in pounds per square inch.

For the range of temperature from 120° C. to 260° C. the pressure of saturated water vapour is given in mm. of mercury to within 0·1 per cent. by the formula :

$$\log p = 8 - \frac{1700}{232{\cdot}22 + t},$$

or, if t_f be the temperature Fahrenheit,

$$\log p = 8 - \frac{3060}{386 + t_f}.$$

Since this range of temperature (248° F. to 500° F.) is the range with which users of saturated steam are largely concerned, this simple formula may be found useful. To obtain p in pounds per square inch the formula becomes :

$$\log p = 6{\cdot}2864 - \frac{3060}{386 + t_f}.$$

II.—Additive Compounds of Nitroaminobenzenes and Anilines.

By Glyn Owen, M.Sc.

During the course of an investigation of the transformation of 2 : 4-dichloronitroaminobenzene into the isomeric 2 : 4-dichloro-6-nitroaniline, Orton and Reed (private communication) noticed that under certain conditions a substance of lesser solubility than these components crystallised out of aqueous solution during the change. This substance appeared to be salt-like, since the components could be separated by forming the sodium salt of the nitroamine, and in this way it was shown that the components were present in equimolecular proportions. The following investigation was undertaken, under the supervision of the late Professor K. J. P. Orton, F.R.S., in order to see whether the formation of such additive compounds was general, as indeed might be anticipated from the pseudoacidic nature of the nitroaminobenzenes.

Nitroaminobenzenes decompose easily even at temperatures below their freezing-points, and this hinders an accurate study of the freezing-point curves of nitroaminobenzene-aniline mixtures, but definite evidence of compound formation was obtained from the diagram of thermal equilibrium which assumed the characteristic double form. When these mixtures were heated orange red colours were developed as soon as the eutectic temperatures were reached. This development of colour rendered observation difficult, and from the eutectic temperature onwards only the heating curve was relied on. Such colours in the eutectic mixtures were shown when aniline, *o*- and *p*-toluidine, 2 : 4-dichloroaniline, 4-bromoaniline, α- and β-naphthylamine were used with 2 : 4-dichloronitroaminobenzene or 2 : 4 : 6-tribromonitroaminobenzene. The develop-

ment of colour was not due to the change of the nitroaminobenzene into the nitroaniline, since the former was completely recovered as the potassium salt from the coloured mixture.

Mixtures of amines and nitro-compounds showing similar behaviour have been observed previously, chiefly by Tinkler [1] who showed, for example, that in the case of p-chloronitrobenzene-diphenylamine mixtures, colour was developed as soon as the eutectic temperature was reached.[2] No compound formation was indicated on his freezing-point diagram, and the colour disappeared on cooling. In the mixtures studied by the present author, cooling did not cause the complete disappearance of colour, possibly owing to the sluggishness of the system in the solid phase, but the colour certainly became much less intense. Other cases have been noted, such as with anilines dissolved in tetranitromethane,[3] while Sudborough has shown that additive compounds are formed between trinitrobenzene and arylamines, which are coloured and which decompose on dilution.

In the present work attempts were made to isolate from solution the compounds indicated on the freezing-point diagram, but no colours developed in the solutions, either on heating for short periods or on long standing at room temperature, beyond a faint yellow that probably indicated slow transformation of the 2 : 4-dichloronitroaminobenzene into 2 : 4-dichloro-6-nitroaniline or of the 2 : 4 : 6-tribromonitroaminobenzene into 2 : 6-dibromo-4-nitroaniline. On mixing chloroform solutions of the components and gradually adding ligroin colourless salts separated out; these compounds gave freezing-points

[1] *J. Chem. Soc.* (1913), p. 2171.

[2] *o*-nitrobenzaldehyde-diphenylamine mixtures also show this phenomenon well. The components on being pressed into intimate contact become orange coloured. Cooling to 0° C. causes fading. Colour is restored when the room temperature is attained.

On prolonged standing *in the light* this mixture becomes blue and finally violet in colour; in benzene solution a green colour develops, changing to a deep violet on standing for some weeks in diffused light. These latter colour changes are probably to be associated with the known photochemical change of *o*-nitrobenzaldehyde to *o*-nitrosobenzoic acid (Ciamician, *Atti R. Accad. Lincei* (1901), (v), **103,** 228).

[3] Ostromisslensky, *Ber,* (1910), **43,** 197; Werner, *Ber.* (1909), **42,** 4324.

several degrees below those indicated on the freezing-point diagrams. Thus the colourless salt of *p*-toluidine with 2 : 4 : 6-tribromonitroaminobenzene had a freezing-point of 92-93°, whilst the compound formed in fused mixtures had a freezing-point of 105° C. The former melts to a coloured liquid ; it is not possible to state the freezing-point after fusion and resolidification, since observations taken on reheated products are liable to large errors in the present class of substances owing to slight decomposition. The fading of the colour on solidification suggests the identity of both products, but the discrepancy between the freezing-points remains unexplained ; recrystallisation of the fused mixtures gives the colourless salts.

These compounds are unstable in the liquid state as are the nitroaminobenzenes themselves. On heating equimolecular mixtures of nitroaminobenzene and aniline to a few degrees beyond the freezing-point a vigorous reaction sets in, during which various products are formed including the parent hydrocarbons. Thus from the mixtures of aniline, *p*-toluidine, *p*-aminophenol, α- and β-naphthylamine with 2 : 4-dichloronitroaminobenzene, both benzene, toluene, phenol and naphthalene are formed in considerable quantity, together with 2 : 4-dichloro-6-nitroaniline and other products. Ammonia was also detected in the case of *p*-aminophenol and the naphthylamines. Oxides of nitrogen were not detected.

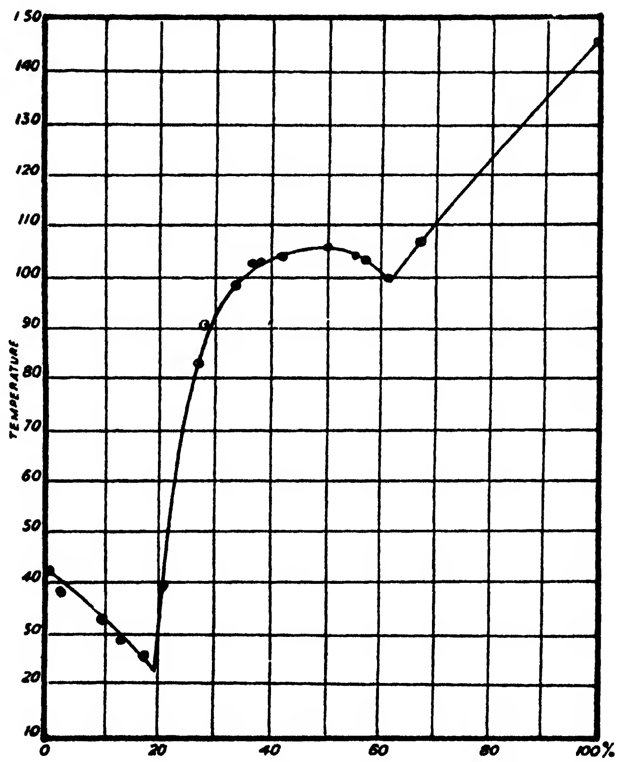
2 : 4 : 6-*tribromonitroaminobenzene* and 2 : 4-*dichloronitroaminobenzene* were prepared according to the procedure described by Orton.[1] When required for use, the crude materials were converted to their barium salts which were then recrystallised ; the free nitroaminobenzenes were then liberated from aqueous solution by cautious acidification with 2 per cent. hydrochloric acid. The recorded freezing-points of 146° C. and 56° C. respectively were confirmed.

The remaining materials were either pre-war Kahlbaum specimens, or were specimens prepared for other purposes in this laboratory. These materials were all either redistilled or recrystallised before use.

[1] *J. Chem. Soc.* (1902), 809 and 965.

Freezing-point curve for the system p-*toluidine*—2 : 4 : 6-*tribromonitroaminobenzene.* — The apparatus and procedure have been described in a previous paper.[1] Quantities of 1 to 1·5 grams were employed for each determination, each mixture being made up separately; in no case was a mixture heated

FIG. 1.
Freezing-point curve for the system
p-toluidine—2 : 4 : 6-tribromonitroaminobenzene.



Molar percentage of 2 : 4 : 6-tribromonitroaminobenzene.

more than once. When visual observation could not be relied on time-temperature curves were taken. On heating, as soon as the eutectic temperature is reached, a bright golden-red colour appears throughout the mass, and its intensity reaches a maximum when mixtures of equimolecular proportions are

[1] *J. Chem. Soc.* (1923), 3394.

employed. At temperatures above 110° no reliable values could be obtained owing to decomposition. The freezing-point of the nitroaminobenzene itself was obtained by sealing a small amount up in a capillary tube and placing it in the heating bath at a temperature about 5° below the anticipated freezing-point. When observed in the open test tube as in the remainder of the measurements, the freezing-point varies greatly, being generally about 20° too low. The following table gives the freezing-points found; "x" represents the molecular percentage of the 2 : 4 : 6-tribromonitroamino-benzene in the mixture. The results are plotted in Fig. 1.

x . .	0·00	2·07	9·57	12·74	17·88	21·09	27·00	28·07
F.P. .	43°	38°	33°	29°	26°	39°	83°	91°
x . .	33·55	36·80	42·00	50·00	54·57	57·07	61·40	67·23
F.P. .	99°	103°	104°	106°	103·5°	103°	100°	107°

It is clear that the formation of a compound is indicated on the curve. Although the temperature could be estimated on the thermometer to 0·05°, the values recorded cannot be regarded as correct to less than 0·5° owing to the unstable nature of the system. Similarly no attempt was made at the observation of eutectic arrests.

Freezing-point curve for the system 2 : 4 : 6-*tribromoaniline*-2 : 4 : 6-*tribromonitroaminobenzene.*—The following were the values obtained: "x" indicates the molecular percentage of 2 : 4 : 6-tribromonitroaminobenzene in the mixture. The results are plotted in Fig. 2.

x . .	0·00	8·06	14·96	20·08	23·70	38·10	46·60	49·92
F.P. .	119°	112°	107°	104°	102°	99°	101°	100°
x . .	59·47	66·43	77·50	100·00				
F.P. .	101°	113°	120°	146°				

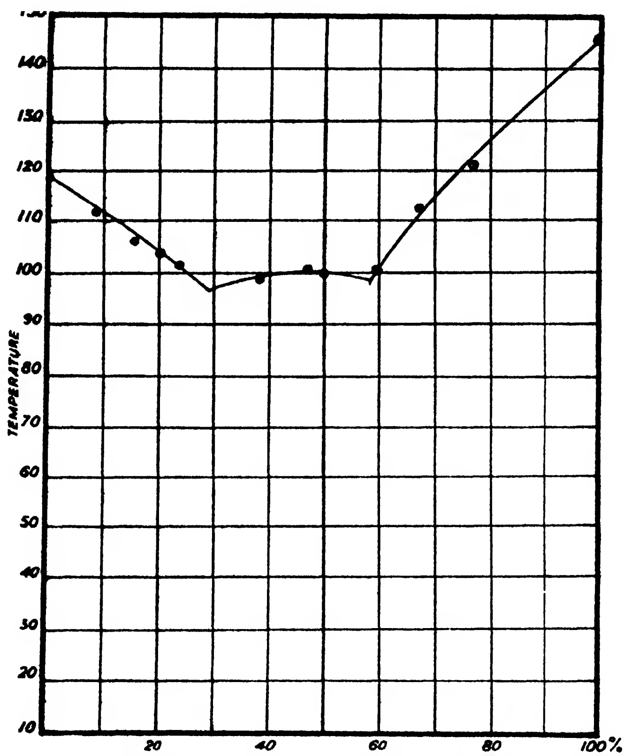
This curve again indicates the formation of a compound, but the curve must be regarded as approximate, since experimental difficulties are enhanced owing to the high freezing-point of the aniline and the ease of decomposition of the compound formed. The shape of the curve indicates considerable dissociation of the compound into its components.

It is noteworthy that the salt usually formed with the aniline in solution could not in the present case be obtained free from the tribromoaniline.

The question of the possible transformation of the 2 : 4 : 6-tribromonitroaminobenzene into 2 : 6-dibromo-4-nitroaniline [1]

FIG. 2.

Freezing-point curve for the system
2 : 4 : 6-tribromoaniline—2 : 4 : 6-tribromonitroaminobenzene.



Molar percentage of 2 : 4 : 6-tribromonitroaminobenzene.

being the origin of the colour developed on liquefaction was investigated by estimating the components afterwards. 0·6500 grams of the aniline and 0·7500 grams of the nitroaminobenzene were allowed to liquefy completely at 104° under the conditions of the experiments for the determination

[1] Orton, *J. Chem. Soc.* (1908), 751.

of the freezing-point curves. The melt was then extracted with chloroform, the 2 : 4 : 6-tribromonitroaminobenzene estimated by titration with alkali and the aniline recovered by evaporation of the chloroform. The chloroform solution required 28·0 c.c. of 0·714 N/10 KOH for neutralisation, corresponding to 99·7 per cent. of the nitroaminobenzene, whilst the evaporation of the chloroform gave a residue of 0·6438 grams of aniline, corresponding to a recovery of 99·0 per cent. of the original material.

The colourless salts were prepared by dissolving equimolecular quantities of the constituents in chloroform and adding ligroin (60-80° fraction) drop by drop, when the compounds separate out in well-defined crystalline form. They do not keep well even in the dark, and their solutions in organic solvents become coloured in the course of a few hours. All the salts answer to the aromatic nitroamine test with concentrated sulphuric acid, giving intense crimson to violet colours which change on the addition of water with the formation of yellow to red precipitates. If, however, the para position is unsubstituted, then the addition of water precipitates a green material from the solution in sulphuric acid.

The salts were roughly analysed by titration with alkali, the salt being dissolved in chloroform. Phenolphthalein was used as the indicator.

Salts of 2 : 4 : 6-*tribromonitroaminobenzene.*—The aniline salt separates in small needles of m.p. 77°. 0·6590 gram required 20·2 c.c. of 0·6900 N/10 KOH . $C_6H_2Br_3NHNO_2$ = 79·3 per cent. $C_{12}H_{10}Br_3N_3O_2$ requires 80·1 per cent.

The *p*-toluidine salt separates in rosettes of fine needles of m.p. 92-93°. 0·3088 gram required 9·05 c.c. of 0·6900 N/10 KOH . $C_6H_2Br_3NHNO_2$ = 75·8 per cent. $C_{13}H_{12}Br_3N_3O_2$ requires 77·7 per cent.

The *o*-toluidine salt is polymorphous and separates in granules which change quickly to fine needles of m.p. 102°. 0·5018 gram required 15·07 c.c. of 0·6900 N/10 KOH . $C_6H_2Br_3NHNO_2$ = 77·7 per cent. $C_{13}H_{12}Br_3N_3O_2$ requires 77·8 per cent.

The *p*-chloroaniline salt separates as fine flattened needles

of m.p. 93°. 0·5668 gram required 16·4 c.c. of 0·6900 N/10 KOH. $C_6H_2Br_3NHNO_2$ = 74·8 per cent. $C_{12}H_9ClBr_3N_3O_2$ requires 74·6 per cent.

The *p*-bromoaniline separates in the same form as the *p*-chloroaniline salt. The m.p. is 106°. 0·5106 gram required 13·2 c.c. of 0·6900 N/10 KOH. $C_6H_2Br_3NHNO_2$ = 66·9 per cent. $C_{12}H_9Br_4N_3O_2$ requires 68·4 per cent.

Salts of 2 : 4-*dichloronitroaminobenzene.*—The aniline salt is polymorphous, and separates initially in plates which change to a needle-shaped modification in the course of two to three hours. The m.p. was 88°. 0·4126 gram required 19·74 c.c. of 0·6900 N/10 KOH. $C_6H_3Cl_2NHNO_2$ = 68·3 per cent. $C_{12}H_{11}Cl_2NO_2$ requires 69·0 per cent.

The *o*-toluidine salt separates in elongated plates of m.p. 77-78°. 0·5078 gram required 23·0 c.c. of 0·6900 N/10 KOH. $C_6H_3Cl_2NHNO_2$ = 64·7 per cent. $C_{13}H_{13}Cl_2N_3O_2$ requires 65·9 per cent. The *p*-chloroaniline salt separates in flattened needles of m.p. 58°. 0·4211 gram required 18·0 c.c. of 0·6900 N/10 KOH. $C_6H_3Cl_2NHNO_2$ = 61·1 per cent. $C_{12}H_{10}Cl_3N_3O_2$ requires 61·9 per cent.

The *p*-bromoaniline salt separates in flattened needles of m.p. 68°. 0·5064 gram required 19·0 c.c. of 0·6900 N/10 KOH. $C_6H_3Cl_2NHNO_2$ requires 53·7 per cent. $C_{12}H_{10}BrCl_2N_3O_2$ requires 54·6 per cent.

The 2 : 4 : dichloro-6-nitroaniline salt separates with great ease in the form of golden plates of m.p. 77°. 0·3355 gram required 11·53 c.c. of 0·6900 N/10 KOH. $C_6H_3Cl_2NHNO_2$ = 49·1 per cent. $C_{12}H_8Cl_4N_4O_4$ requires 50·0 per cent.

III.—The Scientist and the Historian: a Plea for Co-operation.

By B. Mouat Jones, D.S.O., M.A.

Presidential Address.

(Session 1931-32.)

The 150 years during which this Society has existed have witnessed a gradual development in science from a broad natural philosophy into a series of specialised branches. These more or less water-tight compartments, however, while retaining their specialised character, have, especially in the last fifty years or so, vigorously reacted upon, and often merged, into one another. It may be said, indeed, that every branch of science impinges somewhere on every other branch. In some cases the contact may not be very clear, in others it cannot be said where one science begins and another ends.

Broadly speaking, the greatest advances tend to be made across the frontiers where two or more sciences meet, in the borderline sciences.

Much the same may be said of technology. The progressive industries are those which have broken down the imaginary barriers between the pure and the applied sciences, and which have utilised the knowledge, experience and technique of other, perhaps unrelated, industries.

To a much less extent the same process has been going on between the sciences and those branches of study to which the experimental method does not readily lend itself. But the contact is less close, the frontiers less accessible and less easily crossed. Nevertheless, where contact can be estab-

lished, it is to be expected that cultivation of the frontier territories should result in a rich harvest.

Such a borderland seems to be provided by that region where Science and History interact, using the term history in what is now perhaps the commoner sense of events themselves, rather than in its original sense of a record of events. I do not refer at all to the History of Science, but to Science as a part of History. The History of Science is a well-known field in which many have worked and are working. But science as a factor in history appears, to judge from the ordinary history books, to be a possible field of investigation which has been almost entirely neglected. Attention has often been directed towards it, but very little appears to have resulted. I am venturing in all timidity to draw attention to it once again.

I do not know whether a historian, if asked, would be prepared to make a list of the main factors which have operated in the controlling of the course of historical events: or, if so, whether he would risk his reputation by putting them into some sort of order of relative importance. But I should hazard the conjecture that it might be possible to draw up some sort of a list which might contain such factors as these: the elementary need for food and clothing and the more complex desire for luxuries, religious yearnings and irreligious tendencies, the personal ambitions of prince, peer and proletarian, the distribution of minerals and the habits of mosquitoes, the notions of nationalism and internationalism, climate and weather, the cogitations of philosophers and the outpourings of poets. All these things, and a million others, would seem to have had their effect, sometimes great, sometimes small, upon the course of human history. All of them, and many more, are in fact to be found in the history books. But I dare to suggest that a place should be found in the list, and rather a high place, too, for the scientist and his work. I can hardly imagine that anyone would wish to dispute this: the facts speak too insistently for that. But when, in fact, we turn to the history books we find that, with scarcely any exaggeration at all, science has apparently played absolutely no part whatever in the drama of history. The scientist and

his influence on the development of the life, thought and civilisation of peoples are to all intents and purposes utterly neglected. Now, though no one is likely seriously to contravene that statement, it would be seemly to bring some evidence in support of it.

I have examined a considerable series of works on general history, selected for me by competent authorities as typical of those in use in our elementary and secondary schools and in our Universities. I have found [1] either that the influence of scientific thought and discovery upon the development of civilisation is quite unmentioned or unappreciated or that, if any reference at all is made to scientists and their work, no attempt is made to incorporate them organically in the general historical scheme.

I have no wish to make out a case for the place of science in history: certainly not to this society of scientists. For did not my immediate predecessor in office address us on the subject of "What Civilisation owes to this Society," and so stake out for all time the claim of science to an honourable place in history? Moreover, it has already been done sixteen years ago in a lecture on the "Place of Science in History" before this Society by Professor Julius Macleod.

However, the recent centenary celebrations in connection with Faraday's discovery of electromagnetic induction provide forcible illustrations of the points I wish to make. The whole world joined in these celebrations, and Faraday has been universally acclaimed not only an outstanding scientific genius, but a man who has profoundly modified the life and habits and thought of all civilised peoples. And we are still probably only at the beginning of the consequences of his work.

To make comparisons between the historical results of one man's work and those of another in a different field would be proverbially odious and practically futile. But it is at least arguable that as a historical figure Faraday might claim to rank with Napoleon, Gladstone or Queen Victoria, to mention at random three worthies from the same century. But

[1] Illustrated in the Address by reference to actual works.

whereas Napoleon gets his chapters, Gladstone his pages, and Victoria her paragraphs, Faraday rarely achieves a sentence. Nevertheless, it would be no outrageously bold prophet who might suggest that in 500 years' time Napoleon will be remembered only as an extremely able exponent of a certainly barbarous and perhaps extinct art, that Queen Victoria will be but a buxom date in a list of extinct dynasties, while Gladstone, an extinct political volcano, may well have dropped out of the ordinary text-books and become a shadowy figure, whose collars and travelling bag of that ilk provide Ph.D. students with suitable material for profitable research. Whereas it is hard to believe that Faraday can ever be anything but a great scientific, and so a great historic, figure. He is indeed recognised as such now ; he has been recognised as such at any time, in, say, the last fifty years, by everyone except the writers of history books : by everyone except those who, while unhesitatingly writing at length of the doings of contemporary political stars who may after all turn out to be but "hot white dwarfs," can with equal assurance ignore those constellations of scientists who have established themselves as potent, if cooler, "giants."

The historic significance of the individual, however, is perhaps the least important aspect of the subject. Faraday was not an isolated scientific and historic figure—a *nova* suddenly blazing into prominence to lapse again into oblivion. He was an outstanding genius, but like everyone else, he was largely a product of his time. Even more, it is true to say that his work was no isolated achievement ; it was not the mere product of his own brain and experimental skill. Nothing can ever detract from the greatness of his work : nevertheless, it could not have happened without Oersted and Ohm and Volta and Galvani and Gilbert—to mention a few names only in the direct line of descent. Nor could it have happened without the background of new scientific concepts provided by Lavoisier, Dalton, Wollaston, Cavendish, and many another, the founders of nineteenth-century science. And these again were conditioned by their fore-runners, the founders of modern science, dating arbitrarily but conveniently from the time of Francis Bacon, such as Robert Boyle and his contemporaries.

In this sense it would be fair, though by itself misleading, to say that it was Boyle's *Scyptical Chymist,* as much as any other single work, which really made Faraday possible, and which has given us electric trains and wireless and the dye-stuffs industry and all the rest. But where do you ever find a reference to the *Scyptical Chymist* in the history books? The point I wish to make is that science and the scientist have *all the time* been playing a quite fundamental part in the development of thought, in the moulding of material progress, in the evolution of civilisation, in the unfolding of history. But from the history books one would never suspect it.

It would be a simple matter to give innumerable instances of the part played by science in historical development on the material and economic sides of life. It has been done often enough: Perkin's mauve and the dye industry; Pasteur and the health of peoples; Liebig and agriculture; Mendel and stock-breeding; Hertz and wireless; and hosts of other stock illustrations. Indeed, there is perhaps no aspect of the life and habits of the common people which has not been profoundly influenced by the scientist. But we never read about this influence in the history books. If the scientist is mentioned at all, we get a picture of some one quite apart from the ordinary doings of humanity: a picture of a secluded, secret, and probably bearded race, searching after truth for truth's sake in a loveless and joyless cave: a peculiar people, harmless in themselves, perhaps slightly indelicate in their pursuits: of no immediate concern with the workaday world, and much better left alone. Whereas, in fact, the scientist fulfils the functions of normal citizenship by paying an increased income-tax on a decreased income, and in other ways; but he is, in addition, all the time a historic factor reacting upon his fellow-men and their posterity with a vigour and directness vouchsafed to few other classes of mortals.

The industrial revolution affords an interesting episode. This always gets a good notice; but its scientific origin, if it had one, is never referred to. As a matter of fact, I do not know of any specific scientific discovery that can be directly associated with it. There were innumerable inventors: Newcomen, Watt, Hargreaves, Arkwright, Crompton and the

rest, to whom the history books always give a good press. But why this sudden outcrop of inventors at this time? Is it not possible that they were the logical outcome of the new scientific atmosphere, the new spirit of enquiry, the new experimental method adumbrated by Francis Bacon? Is it not possible that the first-fruits of Bacon's philosophy, Boyle, Hooke, Mayow and their successors, in creating this spirit of experimental enquiry, stimulated the inventors and made it possible for their inventive minds to function inventively? Should not Bacon be regarded in a sense as the founder of Britain's industrial supremacy three centuries later? Would it not be more just to refer to the seventeenth and eighteenth centuries as the crucial age of science, rather than, as is always done, the nineteenth?

I do not know the answers to any of these questions, because the history books, which ought to tell me, are silent on such matters.

Let us take war, about which the historians generally have plenty to say as to its origin, conduct, and consequences. It is true that they never fail to describe how Archimedes called science to the aid of the Greeks, and by the use of a reflecting mirror and the laws of optics burnt and utterly destroyed the investing Roman fleet—an episode which I always feel is more historical than scientific.

But what history book ever refers to the fact that the heavy chemical industry owes its origin largely to the Napoleonic Wars and M. Leblanc? And yet that interplay of science and history would appear to have had economic and social consequences worth a bare mention.

Or take the last war. We can read a great deal about its causes—the Drang nach Ost, Panslavism, the Entente Cordiale, and the rest. One can read pages, chapters or books about what happened in July, 1914. But what historian has ever heard of, or thought fit to mention, Davy's first experiments with finely-divided platinum 100 years before—the experiments which opened up the whole field of catalytic action, which led to great industrial advances in many directions, and in particular to the Haber Process for the fixation of nitrogen? Germany admittedly could not, with any hope of success, and

would not, could it be avoided, have gone to war until that process had been perfected, which happened early in 1914. To suggest a catalytic origin for Armageddon may sound far-fetched: it is far-fetched. But a historian will not hesitate to trace with deadly logic the origin of the British Empire to, *inter alia*, the atrocious cooking of our remote forebears, which called for condiments, which fostered trade with the East, which demanded sea-power, which needed coaling-stations, which had to be defended, which needed more sea-power—and so to the British Commonwealth of nations. Is the relationship of a war with the peculiar properties of a precious metal a further-fetched idea than that of an Empire founded on pepper?

Metallurgical science, too, might have something to say on the origin of the Great War. There are trade records which show that in the year before the war Germany suddenly imported certain minerals and metals necessary for special steels and other essential war purposes, which were unobtainable from her own mines or those of her probable allies, to an extent far in excess of her peace-time requirements, and as much as several hundred per cent. above the previous four-year average, and sufficient for a two- to five-years' supply. That, if one is considering the origins of the war, seems to be a fact of prime importance. But I have never seen it mentioned in any ordinary history book: for molybdenum and nickel convey but little to the mind of the historian. What do they know of history who only history know?

Such quite random instances of the relationship of science to history on the material side could be multiplied indefinitely. The part played in the intellectual field, however, is probably of more far-reaching importance. But here it is difficult to demonstrate in a concrete way what one feels must be true.

What, for instance, has been the effect of Newton's discoveries on the general intellectual outlook? It must surely have been immense, but it might be difficult to say exactly how.

With Darwin it is easier. Evolutionary ideas have become part of the mental equipment of every thinking person, and even the least intellectual must have absorbed

something of the Darwinian outlook. Dalton's atomic views, too, must have permeated the general consciousness, and effected a certain preciseness of view, to an extent considerably affecting the general mode of thought of the last 120 years.

In general, the people as a whole must in one way or another have acquired a much more scientifically-directed mind than was possible 100 or 200 years ago. And this must have had important reactions on political, religious and economic thought, and so on the course of history. There must be much more open-mindedness than before, less prejudice, less respect for unsupported authority and unprofitable tradition. Was Karl Marx a product of the new way of thinking, or a die-hard of the old? Is a Mussolini fostered by a scientifically-minded environment or is he a sport? What does Bolshevism owe to Bacon? No one tells me: probably no one knows. But questions of this kind are surely worth answering.

The discoveries of Bunsen and Kirchoff in spectrum analysis which brought the whole universe, as it were, within the field of experiment, must have broadened immensely the general outlook and produced a wholly new mental background. Thompson and Rutherford, Planck and Einstein, and many another have led us to the notion of a curved and kinky space, and of a finite universe expanding in a space-time continuum, created by a Being who, we are told, received his education at Cambridge (presumably Trinity),—a notion which, owing to modern methods of exposition and publicity, is rapidly, if vaguely, sinking into the public consciousness, with a quite inevitable effect on the general attitude towards almost every aspect of life. It is easy to see that it may affect the religious outlook: it is not difficult to see how it may affect the social outlook: it is certain it will affect the course of history.

But is anything of all this ever given a place in the history books? Is an attempt ever made to correlate Cannizaro and Communism, Rutherford and Religion, Planck and Politics? Not at all.

And yet the philosophies of Aristotle and Plato, the writings

of Voltaire and Rousseau, the author of *Uncle Tom's Cabin*, are given their rightful place in the development of political and social history.

A few weeks ago the Bishop of Birmingham stated in a sermon that Liberalism was born of Science : this was promptly denied in a letter to *The Times* by the ex-Bishop of Winchester. Will the historian please tell me which, if either, of these reverend gentlemen is right? And will he tell me, too, whether the internationalism of science has in any way affected the growth of political and social internationalism? If all the world were populated exclusively by scientists—which Heaven forfend!—who always acted scientifically, wars might be expected to cease automatically. For scientists, as scientists, do not settle disputed points by violent attacks upon the persons or laboratories of their opponents : but by patient experimental study of the issues involved, coupled, it may be, with copious polemics of ultra-scientific virulence. What has history to say to this? Has the general spread of a mentality born of science, which recognises no political frontiers, led appreciably to a more general international outlook, a lessening of the risks of war, a strengthening of the cause of peace? Or has the increased power over nature created by the scientist produced another type of mind the bellicose components of which outweigh the more pacific international ones? Have the benefits of science been greater than its dangers? Does history indicate that science is likely, as the President of the Society of Chemical Industry recently suggested, to raise industrial and social problems which neither science nor art may be able to solve? For the guidance of those who are planning for the future, it is important that the historians should attempt to answer such questions. For the past affords the only available evidence upon which to build. It is important not only for the political, social and industrial leaders. It is important that the whole country, the whole world, should be trained to know, in some general way at least, what are the benefits, the functions, the powers, the limitations, and the possible dangers of science. For in a country like this, democratic in name and to some extent in fact, in the long and rather slow run the common people do

in a large measure finally settle matters of large policy. If they are quite unaware of the part played by one of the most powerful and formative forces of history, they are clearly less well-equipped than they might be for arriving at right decisions.

I would urge, therefore, that it is neither out of place nor foolish to ask that our history books, both in our elementary and secondary schools, as well as in our Universities, the books from which the vast majority of the population are going to get the only historical knowledge and all the historical sense which they are ever going to get, should give to science that place which is its due, and which at present it surely does not get.

I do not ask that their pages should be profusely peppered with the names of scientists and what they have discovered. I only ask that the part played by science should be woven into the general fabric of history, its importance as a never-ceasing historical influence be made clear, its relationship to the other characters of the historic drama be disclosed.

It is for this that I plead for the co-operation between the historian and the scientist. My apparent criticism of the history books implies no criticism of the historians, my humble admiration for whom is unclouded by any sort of doubt of their complete worthiness. Nor can any blame be imputed to the scientist. The historian is normally quite innocent of science; and the scientist knows nothing of historical method and technique. Neither alone is capable of giving us histories in which science is afforded its proper place. Co-operation between the two is the only way. Roughly, the scientist would provide the facts, and the historian would weigh them and estimate their significance in the general historic scheme, and give them their appropriate value and place. The result would not be revolutionary, but should be a somewhat more true, and somewhat more complete, picture of human history than we get at present.

The country, and especially the leaders of it, will more and more have to call upon the assistance of the scientist. At present these leaders, while recognising that science has had a place in the historical developments of the past, recognise it all too vaguely; they have no precise knowledge. And, as

always, ignorance leads to fear: fear that if they meddle too much with the scientist they may burn their fingers; fear that should they give the scientist the kind of powers which they themselves possess, they will lose contact and control and be landed in heaven-knows-what unintelligible complications. Anything that could dispel that kind of thing is well worth the doing, and I suggest that it is worthy of the notice of historians, in co-operation with their scientific confrères.

How such co-operation might best be achieved is a matter for much consideration. I am sure it would not be by getting the professors of history and science of a University round a table, with instructions to produce a better and brighter history of the world.

But I have a suggestion to make whereby some small beginning might be made, and in which this Society might take the leading part.

It is no secret that the usefulness and success of this Society have been somewhat impaired by the rise of numerous societies concerned with special branches of science. These naturally claim, and get, the allegiance of their appropriate devotees. And scientists have specialised so intensely that difficulties arise in finding papers or lectures of interest to more than a small proportion of our members at one time.

We are now atthe start of our second sesqui-centennial period, a not inappropriate opportunity for new developments. It has occurred to me that this border-line subject of science and history, for which I have endeavoured to stake out a claim, is one which may perhaps be found to provide something of interest to a majority of our members. I feel that could this Society, should it think it worth while, do something towards stimulating interest in such a subject, it would not at all be contrary to its proper functions and its traditions, and that it might provide itself with some specific objective, in addition to its already existing general activities. I always feel that any Society stands to gain if it has some quite definite and tangible tasks ahead of it. My concrete suggestion is that the Society should arrange for an Annual Lecture, which should have for its purpose the exposition of the part played by science in history. I would make it a

public lecture, as it should not merely be to interest our own members, or the members of other scientific societies, but more especially to arouse interest in the subject among those who teach history in our schools and colleges.

The Manchester Literary and Philosophical Society has itself played an honourable part in the history of science. To assist in an effort to give to science its due place in history would be a task not unworthy of its future nor inappropriate to its past.

IV.—Man's Place in Nature as shown by Fossils.

(Being the Fourth Wilde Memorial Lecture.)

By Sir Arthur Smith Woodward, LL.D., F.R.S.

Seventy years ago Huxley wrote his classic little volume on *Man's Place in Nature*, which explained in simple language the relationship of the human race to the other mammals, and its special kinship to the apes. He enumerated the facts of embryology and comparative anatomy which seemed to show that man must be included in the mammalian Order Primates, which comprises the apes, monkeys, and lemurs in a descending scale. He also concluded that, from the zoological point of view, man had a closer affinity with the higher apes than they displayed with the other Primates beneath them.

When Huxley wrote, however, his argument received very little support from fossils. The remains of extinct apes then known were so few and fragmentary that they were not worthy of mention; and the only skeleton of a fossil man which exhibited some unusual approaches to an ape had been recovered by workmen in a few small pieces from a cave in the Neander valley (Neanderthal), near Düsseldorf, Germany. The top of the skull was especially striking, with its prominent bony brow-ridges and retreating forehead; and Huxley admitted that in all those respects in which the skeleton of Neanderthal man could be seen to differ from that of modern man, it was nearer to the skeleton of an ape. At the same time, this skeleton belonged to a true man, and it scarcely corresponded with the popular idea of a "missing link."

Fossil remains of apes and men must always be rare, for their mental alertness and the circumstances of their life give

them an advantage in escaping the dangers of floods and other catastrophes which have frequently engulfed ordinary quadrupeds and caused their skeletons to be preserved. Observers in the African forests report that when one of the great apes—a gorilla or a chimpanzee—becomes a little feeble and strays from its companions, it usually falls a prey to the leopards. There is thus another possible reason why the remains of their skeleton and teeth, even when accidentally preserved, are in a very fragmentary state. As to man, his bones are so fragile that even when they are in a position favourable for preservation as fossils they are very liable to fracture and decay, and exceptional conditions alone can save them. It is only when man begins to have ideas of a future life, and buries his dead in security, that we can usually hope to recover nearly complete skeletons, and these naturally represent a comparatively late stage in the development of the human frame.

Notwithstanding all difficulties, however, we have now enough fragmentary fossil remains of apes and men to show that in recent geological periods there were fewer differences between them than there are at the present day. We have also good reason to believe that the most man-like apes were of earlier date than the most ape-like men. The evolution of the lower grade into the higher grade thus seems highly probable. This probability becomes the more nearly a certainty, the further we examine the facts and compare them with the facts already discovered in the evolution of the lower mammals which are known by great collections of satisfactory fossils. I think, indeed, we now begin to see that man is not only the inevitable culmination of the procession of life which fossils reveal, but has reached his present position in conformity with principles or laws which are recognisable in the evolution of the rest of the animal kingdom.

Consider, for example, the general succession of the back-boned animals which are adapted to live on land. They seem to have evolved from fishes about the middle of the Devonian period, when there was a mysterious drying up of large areas of the earth's surface. They began with feeble

five-toed limbs, and still breathed by gills in water when they were young, only breathing by lungs when full-grown, like a modern newt. The first step onwards was the complete loss of working gills and the perfection of breathing by lungs. When this had been achieved by the end of the Carboniferous period, backboned animals could leave the swamps, and they were ready for the next advance. This was the strengthening and modification of the limbs for running on hard ground and for scrambling in forests. It led to more variety in the jaws and teeth, and sometimes to the use of the limbs for capturing or manipulating food. Such animals spread over all the warmer habitable regions of the world and occupied them until the end of the Cretaceous period. Like the ancestral fishes and swamp-dwellers, they still had only cold blood—they were, in fact, Reptiles—and when great disturbances of the earth's surface and a widespread lowering of temperature occurred at the end of the Cretaceous and beginning of the Tertiary period, nearly all of them disappeared. Then followed the next advance. Small quadrupeds with warm blood, or Mammals, began to swarm over the nearly vacant lands. Their ancestors had probably been living and evolving in the upland forests, and only rare fragments of them had previously been washed down into sediments which could preserve them as fossils. These mammals, with their warm blood, now began to show an entirely new development, namely, a rapid improvement in the brain which had previously remained almost stationary in size and plan; and during the Tertiary period they acquired the intelligence with which we are familiar in the modern world. Each of the groups which progressed to occupy a special sphere showed a marked increase in the relative size and complexity of the brain. The greatest advance in this respect happened in the monkeys and apes, which continued to flourish in the forests and by that time needed no change in the limbs and teeth, which were already well adapted to their circumstances of life. Latest of all appeared man, whose brain may be described as an overgrowth of that of an ape.

Now, it has been repeatedly observed, while tracing fossils through a succession of rocks, that when one organ begins to

grow relatively large it tends to continue its growth to excess —it may even become a hindrance rather than an advantage. The upper canine tooth of the "sabre-toothed tigers" (*Machaerodus*, etc.), for example, eventually became so large that it must have grown beyond its useful size. The antlers of the extinct Irish Deer (*Cervus giganteus*) and allied species became remarkably unwieldy, and the tusks of one of the American mammoths (*Elephas imperator*) must have proved a burden even to an elephant. The eventual overgrowth of the brain in one of the latest mammals is therefore not surprising, but in accordance with a well-established principle. The circumstance is only unique because this overgrowth leads to the dominance of mind in man, and starts a new era in the world. Other overgrowths seem generally to have helped in ending the career of the races in which they occurred.

Man, however, is not only the natural outcome of the evolution of the mammals as revealed by fossils. The few fragments of the earliest human skeletons hitherto discovered show that his special feature—the overgrown brain—occurs in its primitive state in at least three or four different kinds of fossil human skulls. There were, therefore, several approaches to modern man before his final form was reached, and only the one successful line with which we are familiar has survived. There appear to have been parallel lines of human development in which the overgrowth of the brain took place independently. Exactly similar parallel developments have long been known among the ordinary mammals. Among the horses, for example, as they are traced through the successive deposits of the Tertiary period, there is a general tendency for the little four-toed dwellers in marshy land, with crushing teeth, to pass gradually into the larger and more alert one-toed horses, with grinding teeth, fitted for life on plains. The evolution, however, takes place independently in different localities, in several parallel series, all changing in approximately the same way, but the corresponding characters of the different series not all changing at the same rate. Hence the variety of the horses in each successive grade, and the much-discussed difficulty of making out exact pedigrees. Hence, moreover, the hopelessness of

discussing the details of the human pedigree with our present scanty material.

I have just mentioned the increase in bodily size which is observed in the representatives of the horses at successive periods of geological time. Such increase in size occurs universally during the evolution of the different backboned animals, and some of the latest and highest members of each group are always the largest. It is therefore interesting to notice that the modern gorilla and man, the latest and highest of the Primates, are larger than any of the known apes which preceded them, while the largest individuals among modern men exceed even the gorilla in size.

When the few known fossil fragments of apes and men are compared in detail, the student of extinct animals again recognises evolution in conformity with several familiar principles.

The skull of a modern ape is readily distinguished from that of a modern man not only by its smaller size and relatively much smaller brain-case, but also by the preponderance of the face and jaws. In the full-grown ape, the temporal muscles which help to work the lower jaw extend so far upwards and backwards that they produce longitudinal bony ridges or even a single crest on the roof of the brain-case and a similar transverse crest across the back of the brain-case; in strange contrast to the smoothly-rounded condition of the brain-case in man, which is due to the less extension and strength of the corresponding muscles. In the ape the orbits grow forwards so much that prominent bony brow-ridges (or at least a thickening of the bone of the brow) are needed to form a roof for them; [1] in man the orbits are beneath the front part of the brain-case, and there is a deep upright forehead. In the ape the row of teeth on one side of the jaw is nearly parallel with that of the other side, and the canine tooth of each side forms a prominent cone which works against an equally prominent tooth in the opposing jaw; in man the teeth of each jaw are arranged in a horseshoe-shaped

[1] L. Bolk, "On the Significance of the Supraorbital Ridges in the Primates," *Proc. Roy. Akad. Sci.*, Amsterdam, Vol. XXV (1922), p. 16.

row, and the canine does not project beyond the rest of the teeth. In the large lower jaw of the ape the tooth-bearing border is necessarily very long, and the heavy bony chin slopes downwards and backwards; in the small lower jaw of man the tooth-bearing border is shortened by shrinking, and the bony chin is thus left nearly upright, usually with a little forward prominence below.

Unfortunately, no skull of an early ancestral ape is yet known, but some of its characters can be inferred from the fragments of jaws and teeth which have been discovered in Europe, Asia, and North Africa. The oldest known lower jaw, from the Oligocene rocks of Egypt (*Propliopithecus*), is comparatively small, with a very short and delicate bony chin, and the canine teeth only slightly prominent. The heavier and larger lower jaws of *Dryopithecus*, from the Upper Miocene and Lower Pliocene of Europe and India, represent animals about as large as a chimpanzee, but still have a very short bony chin, with the canine teeth considerably smaller and less prominent than those of any existing ape. These fossil apes, therefore, presumably had a shorter and smaller face than the modern apes, with the orbits not yet thrust forwards but beneath the front of the brain-case. The skull would thus lack bony crests or ridges, on account of the comparative feebleness of the temporal muscles, and there would be no bony brow-ridges. The whole aspect of the smooth ovoid skull, the face, and the jaws would, in fact, be much like that of an immature modern ape before it has shed its first set of teeth. Now, as shown by fossils, the very young state of an animal often gives clues to the nature of the immediate ancestor from which it has evolved. Therefore, *Propliopithecus*, *Dryopithecus*, and their contemporary allies, may almost certainly be regarded as among the ancestors of modern apes, and they would serve equally well as the ancestors of man. If, without much expansion of the brain, their orbits grew forwards, and their face, jaws, and canine teeth enlarged, they would pass into modern apes; if their brain much increased in size, their orbits remained beneath the brain-case, and the jaws and canine teeth became reduced, they might pass into man. *Dryopithecus*, indeed, has lower molar teeth in pattern very like those of the fossil Piltdown man.

It may be added that some of the ancestral apes may have survived with little change until comparatively modern geological times. *Australopithecus*, for example, from South Africa, may perhaps be such a survival, but it is only known by one imperfect skull with lower jaw of a young individual retaining the temporary teeth of the first set. The so-called Pleistocene apes and ape-men which Freudenberg[1] finds among the fossil bones in the well-known sand-pit of Mauer, near Heidelberg, are in my opinion due to the wrong interpretation of indeterminable fragments.

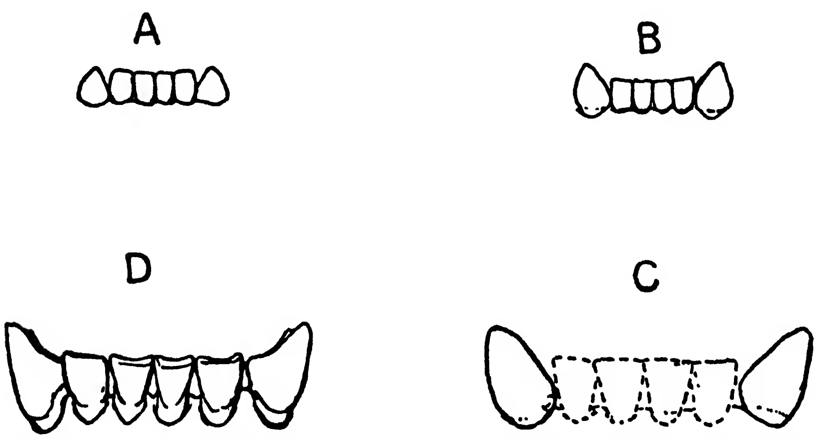
The only fossil hitherto discovered which is so near the limit of both ape and man, that it is sometimes referred to the one, sometimes to the other, is the top of the skull named *Pithecanthropus*. It was found by E. Dubois with other mammals in a Lower Pleistocene river-deposit in Java. Viewed from above, it looks like the skull of a gigantic gibbon, with very prominent brow-ridges; but the brain seems to have been as large as the smallest modern human brains, and it is described as having specially human characters. With the piece of skull were discovered isolated teeth and a straight thigh-bone, which also seem to be on the whole human. Long and careful search in the same river-deposit has unfortunately still failed to obtain any further remains.

An essentially human skull from a river-deposit near Piltdown, Sussex, is probably as ancient geologically as *Pithecanthropus*, yet is totally different and exhibits other resemblances to the skull and lower jaw of the apes. It seems to me to represent a real "man of the dawn," and I have accordingly named it *Eoanthropus*. The brain-case is remarkable for the absence of bony brow-ridges, implying that the orbits remained throughout life as completely beneath the front part of the brain as in modern man. It is, however, depressed in shape, with an especially wide and squat occiput, and an unusually broad base; and markings show that the temporal muscles spread upwards further than ordinarily in a human

[1] W. Freudenberg, "Die ersten Primatenfunde von Bammental bei Mauer a.d. Elsenz aus praeglacialen Neckarkiesen.," *Verhandl. Ges. Phys. Anthropol.*, 1929, p. 68. See also *Zeitschr. deutsch. geol. Ges.*, vol. 83 (1931), p. 642.

skull. The general shape of the brain-case, indeed, approaches that of a young modern ape, and is therefore presumably very like that of the ancestral apes. The brain is as large as that of some of the existing lower races of men, about 1300 c.c. in bulk, but according to Professor Elliot Smith it is the lowest type of human brain hitherto discovered. The deep socket for the articulation of the lower jaw, and the shape and size of the mastoid process, are of the modern human pattern. The nasal bones are also typically human, though of low grade. The skull, therefore, exhibits a curious mingling of some of the traits of an ancestral ape with those of a modern man. At the same time, it differs from both ape and man in the peculiar texture of its unusually thick bone. This bone consists of very fine spongy tissue between an extremely thin outer and inner hard layer, which would cause the skull to be particularly resistant to blows without cracking. The lower jaw, which shows that the face was very much larger than in modern man, bears more resemblance to the lower jaw of an ape than any jaw hitherto discovered in association with an essentially human skull. If the bony ramus of this jaw had been found isolated and without teeth, it could only have been referred to an ape. It exhibits the characteristic retreating chin of an ape, with the thin inward flange at the base; it bears no mark of the floor of the mouth; the mylohyoid groove is separate and well below the dental foramen; and the area of insertion for the temporal muscle is much broader than ordinarily in man. The molar teeth, however, are typically human, with thick enamel and a large pulp-cavity: they are merely unusually large. The premolars and incisors are unknown, but the canine is much enlarged and prominent, and it is worn in such a way as to show that it interlocked with the opposing tooth, as in an ape (Figs. C, D). At first sight, in fact, it seems as if the only human feature in the jaw were the structure of the molar teeth. Further examination of the state of wear of the teeth, however, proves that the permanent canine tooth came into use before the permanent molars exactly as in man, the reverse of the order in the apes. Comparisons also show that this canine differs in the shape of the base of the crown from every

known canine of an ape, whether temporary or permanent, whether recent or fossil. They show still further that the shape and proportions of this tooth are almost identical with those of the temporary canine of modern man (compare Figs. B. C). Now, if the bone be cut away from the edge of the lower jaw of a child in which the temporary teeth remain in position, it will be observed that the canine is relatively large and does not come completely out of the gum (Fig. A). The base of the crown (or neck of the tooth) remains down in the socket below the level of the neck of the incisors. If it



Diagrammatic front views of the lower incisors and canine teeth, showing that if the milk dentition of modern man (A) were modified by the complete extrusion of the canines (B), this would resemble the permanent dentition of Piltdown man (C) more closely than does the permanent dentition of any ape, such as the chimpanzee (D) ; three-quarters natural size.

rose to the same level as these teeth, its apex would project well above the other teeth, and would interlock with its fellow of the upper jaw (Fig. B). In other words, the temporary front teeth of the modern human child are of the same pattern as the permanent front teeth of Piltdown man. In modern man this particular type of canine is superseded and replaced by one of another type in the permanent set which follows. In his front teeth modern man, therefore, advances a step further than the ancestral or dawn man, and retains only a reminiscence of the latter in his temporary set of teeth. It has been known for many years, from many instances, that

the temporary set of teeth of any mammal is approximately of the same pattern as the permanent teeth of its immediate forerunner and presumed ancestor. Through the Piltdown discovery, therefore, man is now proved to conform to the same principle or law.

Two other discoveries of human remains have already been made in deposits which are probably as old as those from which *Pithecanthropus* and *Eoanthropus* were obtained. Firstly, there is an isolated lower jaw from a river sand at Mauer, near Heidelberg, which exhibits a typical set of human teeth, without any enlargement or prominence of the canine; only the bone is remarkably massive, and the chin slopes downwards and backwards, rather in ape-fashion, to a typically human lower border. Secondly, and more recently, several fragments of a nearly similar lower jaw have been found in a cave deposit near Peking, in China, associated with a nearly complete skull and also a more fragmentary skull, which Dr. Davidson Black recognises as representing another extinct genus of man, *Sinanthropus*. This Chinese fossil skull, which is nearly complete apart from the face, has about the same brain-capacity as the Piltdown skull, and agrees with my restoration of the latter in the unusually great width of its base and the peculiar shape of its squat occiput. It also agrees with the Piltdown skull, and differs from every other known skull, in the remarkably fine spongy texture of the thick bone. It is therefore interesting to note that *Sinanthropus* differs completely from *Eoanthropus* in the brow-region, having great bony brow-ridges as large as those of *Pithecanthropus*. In short, in the skull and lower jaw of *Sinanthropus* there are combined some features of each of its three known human contemporaries.

From these facts it is obvious that at first the human brain was associated with various types of skull, jaw, and teeth. There was the parallel development in the early stages to which I have already referred. Even later, when man had begun to take care in burying his dead and thus preserved nearly complete skeletons which we are sometimes fortunate enough to find, there are clear indications of other parallel developments before the modern type of man became fixed.

Neanderthal man, for example, which is now known almost completely by many good fossil remains, possessed a skull and a lower jaw which are different from any of those of earlier date. As shown by Professor Marcellin Boule, who described a fine skeleton from a burial place in the cave of La Chapelle-aux-Saints in the Corrèze, France, the skull in this human race is relatively larger than that of any other known man, and the size of its brain must have been larger than that of the average existing European. Here the overgrowth of brain is especially striking, and, according to Professor R. Anthony, it is characterised by quantity rather than quality. It is an example of the premature and precocious development of a new character, such as is often observed among fossil remains of the lower animals. The chief expansion of the skull is due to a large, depressed, bun-shaped protuberance behind. The orbits are far forwards and roofed by great bony brow-ridges, and the face is relatively larger than that of modern man, though entirely human and with typically human teeth. The mouth is naturally rather large, and the tooth-bearing border of the lower jaw is not so much shrunken as in modern man; hence there is no lower prominence of the bony chin. In the body-skeleton of Neanderthal man it is interesting to notice that the S-curve of the backbone is less marked than it is even in the lowest races of modern man, while the stout arched thigh-bone and relatively short tibia are somewhat more ape-like than those of any man now living.

Finally, Rhodesian man, which probably flourished at a still later geological period than Neanderthal man, exhibits a primitive human brain, associated with a more modern type of skeleton. Only one well-preserved skull is known from a cave in Northern Rhodesia, where there is nothing definitely to fix its date. It was found in association with some typically human limb bones and with stone implements such as were being used in Africa when Europeans first visited the country. With it were also numerous remains of modern African animals. On the whole, the brain-case of Rhodesian man is most like that of the existing Australian black, and his primitive brain would need no more expansion in certain

directions to produce an Australian type of brain than it would need to evolve into a Neanderthal brain. The orbits, however, are situated so far forwards that they are surmounted by enormous bony brow-ridges—the largest ever seen in a human skull; and the face is so large and inflated, that at first sight it suggests an early condition of that of Neanderthal man. It is only after more detailed study and comparison that this unique face becomes more plausibly interpreted as a secondary overgrowth of the Australian type. Both the palate and the teeth are more modern than those of Neanderthal man, and the face is not enlarged in ape-fashion, but by growth round the periphery of a primitive human face. The depth and breadth of the bony muzzle below the nose are especially noteworthy, and the only known skull in which there is any close approach to this development is the fossil Australian skull from Talgai in Queensland. In this connection it is also interesting to add that the few limb bones found with the Rhodesian skull exhibit no essential differences from those of a modern Australian. I am, therefore, disposed to regard Rhodesian man as related to the ancestors of the Australian blacks who must once have inhabited the southern Asiatic and African regions, and I should not be surprised if closely similar races with a normal human face were found in deposits in Africa contemporaneous with those of the Rhodesian cave. If this conclusion prove correct, the face of Rhodesian man becomes an illustration of Dollo's law of the irreversibility of evolution, which is shown by fossils to apply very widely —if not universally—to lineages of animals. The face having become reduced to human size and shape, and then enlarged again nearly to the dimensions of that of a gorilla, the return to the gorilla-character is not exact in any detail. The bony brow-ridges are not continued above the top of the nose, as they are in the gorilla, and there is no alteration in the completely human conformation of the nasal bones and narial opening. There is merely the inflation of the maxillary bone below the eye which necessarily results from its enlargement.

To sum up, then, we have seen that man appeared at the end of a series of mammals in which the brain was evolving at a disproportionate rate. The overgrowth of his brain,

therefore, which is his distinctive feature, is exactly what might have been expected from our knowledge of the fossil lineages of other animals. This dominating brain is already known to occur in several different types of human skulls. There were thus several approaches to modern man before a successful type was fixed and became the sole survivor. There were, indeed, parallel lines of evolution precisely as among other mammals. The few known fossil fragments of apes and men also show that at first there were smaller differences between them than there are in the modern world. They even furnish examples of the familiar "law of recapitulation," or the temporary retention of ancestral features in the early life of each individual; of Dollo's "law of the irreversibility of evolution"; and of the precocious development of new characters such as is often observed among the lower mammals. We may perhaps go one step further and conclude, that just as the successive fundamental advances among the lower backboned animals occurred at geological periods when there were remarkable world-disturbances and widely spread difficult conditions, so man appeared during the latest disturbance when he had to contend with the rigours of the Great Ice Age.

V.—Some Experiments on Flame Movements in Gaseous Mixtures.

By Colin Campbell, D.Sc., Clifford Whitworth, M.Sc., Ph.D., and Alfred King, M.Sc.

Part I.—The Movement of Explosion Waves in Gases contained in Tubes of Non-uniform Diameter.

By Colin Campbell, D.Sc., and
Clifford Whitworth, M.Sc., Ph.D.

The explosion wave in any gaseous mixture travels with constant velocity in a long tube of uniform bore [1] provided that measurements are not made near the point of detonation, where the velocity is often much higher.[2] At a point where an abrupt increase in the diameter of the tube occurs the explosion wave is damped down [3] and the flame in the wider portion of the tube often travels a considerable distance before detonation is again established.[4] Some further experiments on the lowering of velocity of the flame at a junction of two tubes of unequal diameter show that the increase in tube-diameter necessary to damp down the detonation wave depends on the explosive mixture used. In the former paper [5] it was shown that, using the mixture $2H_2 + 3O_2$, an increase in diameter from 10 mm. to 22 mm. (i.e. bore-ratio 2·2) was able to reduce the flame velocity from 2120 to 890 m. per sec. With a stronger mixture, $2H_2 + O_2$, it is now found that an increase in diameter from 10 mm. to 19 mm. (ratio of bore 1·9) produced a very slight fall in velocity and that detonation was re-established within a very few centimetres. In a number of different mixtures of acetylene and oxygen, the effect of

[1] Berthelot, *see* Dixon, *Phil. Trans.*, A, **184,** 1893, p. 99.
[2] Campbell and Woodhead, *J.C.S.*, Dec., 1926, 3017; Bone and Fraser, *Phil. Trans.*, A, **230,** p. 373, 1931.
[3] Campbell, *J.C.S.*, 1922, **121,** 2483.
[4] Laffitte, *Annales de Physique*, X, iv, 1925, 630.
[5] Campbell, *loc. cit.*

the composition of the mixture on the bore-ratio necessary to damp out the explosion wave is very marked. For instance, a bore ratio of 1·9 was capable of damping out detonation in the mixture containing 9 per cent. C_2H_2, but with stronger mixtures, containing respectively 16·8 per cent., 25 per cent., and 50 per cent. C_2H_2, the explosion waves were not damped out even when the tube ratio was approximately 5·5. It

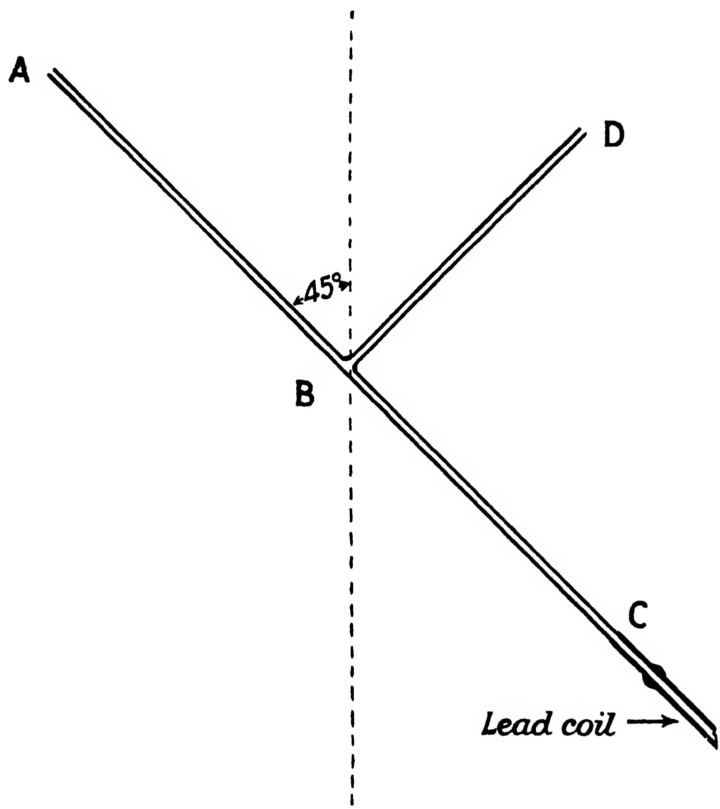


FIG. 1.

was found, however, that a tube ratio of about 5 was sufficient to damp down the explosion waves in the following mixtures: $2CO + O_2 + 1\ \%\ H_2$, $CO + N_2O$, $C_2H_4 + 3O_2 + 3CO_2$, $C_2H_4 + XO_2$, where X varied between 10 and 18.

In all these experiments with wide tubes the apparatus was completely and very violently shattered and the continuation of the investigation became very difficult in the

small laboratory available. It was thought possible to obtain some further information on the effect of increased diameter on the behaviour of different mixtures by measuring the velocity along the arms of a T-shaped tube. The detonation wave, established in a lead coil, passed along CB. (Fig. 1); at B, two paths were open to the flame and the tube BD was in essence a tube of greatly enlarged diameter. By inclining the two branches BA and BD, 75 and 60 cm. long respectively, at angles of 45° to the vertical, the velocity (V) of the flame in each branch could be calculated from the formula: $V = \frac{W\mu}{\cot\alpha - 1}$, where W is the velocity of the photographic film, μ the magnification produced by the lens system, and α the angle between the flame edge and the vertical. The photographs show that with certain mixtures there is no change in velocity in either limb; with other mixtures there is a fall in one limb only, usually BD, and finally with a third group of mixtures there is a damping down of the explosion wave in both limbs. Some of the results have been collected in Table I.

TABLE I.—Damping down of Detonation Wave in

Neither Limb.	One Limb Only.	Both Limbs.
$2H_2 + O_2$		
$C_2H_4 + 8O_2$	$C_2H_4 + 15O_2$	$C_2H_4 + 21O_2$
$C_2H_4 + 10O_2$	$C_2H_4 + 18O_2$	
$C_2H_4 + 13O_2$		
$2CO + O_2 + 2\% H_2$		$2CO + O_2 + 1\% H_2$
$CH_4 + 5O_2$	$CH_4 + 6{\cdot}5O_2$	$CH_4 + 7O_2$

In the ethylene-oxygen mixtures, dilution increases the tendency of the detonation wave to be damped down. Earlier work [1] has shown that photographs, taken on a rotating-drum

[1] Campbell and Woodhead, *J.C.S.*, July, 1927, 1572; Campbell and Finch, *J.C.S.*, August, 1928, 2094.

camera, of the explosion waves in certain gaseous mixtures exhibit undulations in the trace due to the wave front and nearly horizontal bands or "striæ" corresponding with periodic illumination behind the wave front. It is interesting to note that those mixtures which, in the present experiments, show a reduction in flame velocity in one or both limbs of the T-tube are also those which give well-defined striæ. This parallelism applies to mixtures given in Table I, and also to a number of others. For example, the mixture $C_2H_4 + 3O_2$ does not show striæ and presumably would not show damping down in either limb. When CO_2 is added a mixture is finally obtained which is damped down and the same mixture also shows striæ.

At present we are not in a position to suggest why this parallelism should exist, but other experiments, now in progress, all seem to indicate that mixtures which show striæ are, so far as the continued propagation of detonation is concerned, in a much less stable state than those which do not exhibit this phenomenon.

EXPERIMENTAL.

The mixtures were stored over water and passed, without drying, into the explosion tubes which had previously been evacuated. In the first series of experiments, the lead coil (2·5 metres long, near the closed end of which the mixture was sparked) and the first glass tube were both 1·5 cm. bore. The glass tube fitted into a central hole in a large rubber stopper which held the wider tube. No difference in the speed of the flames occurred if the hole was placed eccentrically. The wide tube was open at the further end. The photographs were obtained by means of a rotating-drum camera driven at a peripheral speed of about 40 m.p.s.

In the T-tube experiments, the tubes BA and BD were both open, and, because of their upward slope, hydrogen diffused out very rapidly; in order to get reproducible results, mixtures containing hydrogen were fired with as little delay as possible after the stoppers, inserted before evacuation and filling, had been removed. No marked difference in the re-

sults was noticed if the stoppers remained in position, except that "damped-down" flames set up detonation again more quickly than if the tubes were open.

Part II.—Pressure Conditions ahead of Flames.

By Colin Campbell, D.Sc., and Alfred King, M.Sc.

When a gaseous mixture is ignited in a spherical vessel fitted with a soap-bubble manometer, the soap-bubble is expanded before the flame reaches it [1] and this is explained on the assumption that a pressure-gradient exists in front of the flame. Grice and Wheeler [2] have shown that when a mixture is ignited in the larger of two spheres connected by a narrow passage, the pressure in the smaller vessel, once the gas in it has been ignited by the flame from the larger one, is greater than would have been the case if the smaller vessel alone had been used. This result is explained on the assumption that gas surges from the larger vessel into the smaller one and that there is a piling up of pressure in front of the flame.

It has been suggested by Bone and Fraser [3] that the auto-ignitions ahead of a pre-detonation flame—previously noted by Campbell and Woodhead [4]—were due, at least in part, to a pressure-gradient ahead of the flame. In the following experiments it is shown by visual and photographic means that when a gaseous mixture is ignited near the closed end of a horizontal tube, increased pressure conditions exist a considerable distance in front of pre-detonation and slow flames but not for any appreciable distance in front of detonation waves.

The experiments were carried out in glass tubes, 1·5 cm. bore, firmly clamped in a horizontal position. A thin piece of mica was moistened and made to adhere to one end of the tube; it could be detached by a static pressure of about

[1] Ellis, *Fuel in Science and Practice*, 1928, p. 198.
[2] "Safety in Mines Research Board Paper," No. 49, 1928.
[3] *Phil. Trans.*, A, 230, p. 371. [4] *J.C.S.*, Dec., 1926, p. 3013.

2 mm. of mercury. It was not detached, however, by the passing of a spark at the further, *closed* end of a tube 150 cm. long when the latter contained either air or a very dilute carbon monoxide-oxygen mixture which did not ignite. If ignition in the mixture $2CO + 6\frac{1}{2}O_2$ was started by a flame at the *open* end of the tube, the flame travelled steadily to the diaphragm without displacing it, though the mica vibrated as if relieving, by this means, a slight pressure. If now the same mixture was ignited by a spark near the *closed* end of a tube 190 cm. long, the mica was displaced when the flame was still about 150 cm. from it. It would appear that owing to the firing end of the tube being closed, the pressure generated could not find an outlet behind the zone of combustion and therefore spread in front of the flame which was moving quite slowly, say 50 cm. per second.

In order to discover whether similar pressure conditions existed in front of more rapidly moving flames, these were photographed by means of a moving-film camera, the drum of which was rotated at peripheral speeds varying between 6 and 60 m.p.s., according to the actinic power of the different flames. The explosion tube was placed horizontally directly pointing towards the lens; on the end of the tube nearest the camera was placed the mica, now half-blackened so that the light from the flame passing through a horizontal slit between the tube and the camera was only photographed over half the field. When the mica disc was displaced by pressure the image of the flame suddenly became much wider. In order to obtain a separate measurement of the moment when the flame itself reached the end of the tube, a small mirror was placed in a vertical plane inclined at an angle of 45° to the axis of the tube so that a reflected image of the flame was obtained when it came within 2 cm. of the end of the tube; the direct and reflected images were recorded side by side on the moving film.

The record shown in Fig. 2 was obtained when the mixture $2CO + O_2$ (moist) was ignited by a spark at a point 10 cm. from the closed end of a tube 120 c.m. long. The lower narrow band of illumination corresponds to the travel of the flame in its early stages; the sudden widening of the band of

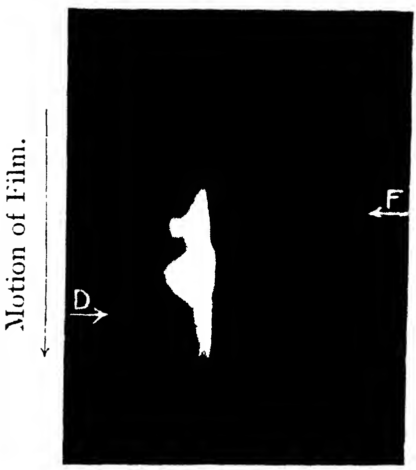


FIG. 2.

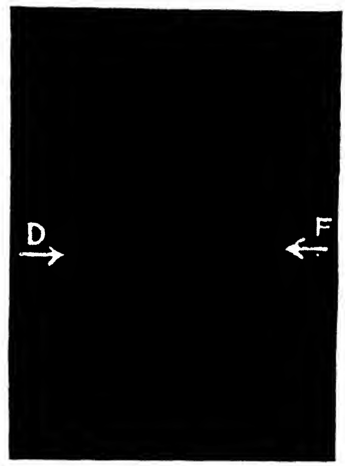


FIG. 3.

[To face page 50.

light, at D, shows the moment when the diaphragm was displaced, and the image, at F, indicates that at which the flame reached the end of the tube. The distance between D and F corresponds, in three closely agreeing experiments, to 0·003 sec. By taking a photograph under exactly the same conditions, except that the tube had been rotated through 90° and was now at right angles to the axis of the camera lens, it was possible to measure the forward velocity of the flame. At a time 0·003 sec. before the flame reached the end of the tube it was approximately 75 cm. distant from the mica disc and travelling at a velocity of the order of 100 m.p.s. It appears, therefore, that there is an increase of pressure at the end of the tube when the flame is still 75 cm. away.

In order to determine whether pressure existed ahead of a detonation wave, a lead coil 3·75 metres long and of 1·5 cm. bore was used as the first portion of the explosion gallery; the mixture, sparked at the further, closed, end of the lead tube detonated in this tube and the flame passed directly into the glass tube which was pointing towards the camera. The record obtained when the mixture $2CO + O_2 + 1\ \%\ H_2$ was used, is shown in Fig. 3. The film was travelling at about 60 m.p.s. and the diaphragm was displaced at almost the same moment as the flame reached the end of the tube. From careful measurement of the photograph it seems clear that the interval of time between the arrival of any pressure and the flame at the end of the tube was not greater than 0·00002 sec., and, since the flame was travelling at about 1750 m.p.s., it must have been within at least 3·5 cm. of the mica disc before the latter was displaced. A similar result was obtained when the detonation wave in the mixture $2H_2 + O_2$ was used instead of that in the mixture $2CO + O_2 + 1\ \%\ H_2$, and, since these are typical of mixtures which respectively do not show and do show well-marked striæ in the ordinary method of flame photography, it seems reasonable to assume that these results are typical of others.

The conclusion that pressure conditions exist ahead of "slow" flames but not ahead of detonation waves seems to accord well with the experiments of H. B. Dixon, who showed

photographically that a detonation wave travelled with unaltered velocity until it collided with the closed end of a tube and that there was no change in velocity of two approaching detonation waves prior to their collision.

In conclusion the authors desire to thank Mr. Norman Calvert, M.Sc., for assistance with some of the experiments described in Part I, and to acknowledge a grant from Imperial Chemical Industries Ltd. towards the expenses of the research.

VI.—Some New Tests Designed for use in the Estimation of Musical Capacity.

By H. Lowery, Ph.D., F.Inst.P.

I. Introduction.

In previous papers [1] it has been suggested that, in any attempt to estimate the musical capacity of individuals, the tests applied should be constructed, as far as possible, from musical material. To the uninitiated, such a suggestion seems to be a statement of the obvious; experience, however, shows that, as a result of the vast amount of experimental research on the psychology of hearing and the consequent analysis of the process of hearing into perception of pitch, rhythm, time, etc., it is easier to construct tests of the modes of functioning of isolated psycho-physical dispositions than to frame tests in order to examine the reactions of the mind to the relatively complicated situations created by musical notes in harmony or melody. It is not intended to disparage the separate examination of psycho-physical functions; this naturally has an important place in the psychology of hearing.

The necessity for the construction of tests of musical ability from musical material arises from a variety of causes. Thus, while pitch, rhythm, quality, time, accent, intensity, and fusion are noticeable as distinct factors in a musical performance, and while demands are made on the listener's mind calling forth, for example, the exercise of *memory*, musical perception cannot be regarded as the mere sum of these various particulars, that is to say, by testing an individual for perception of isolated factors such as pitch discrimination, threshold of intensity, and so on, one is not thereby entitled

[1] *Brit. Journ. Psy.*, Vol. XVII, p. 111 (1926); Vol. XIX, p. 397 (1929); *Journ. of Educational Psy.*, Vol. XX, p. 584 (1929).

to say that 100 per cent. efficiency in each factor implies musical talent in the highest degree. Music teachers are well acquainted with individuals who show marked perceptive powers in regard to certain of the predominant elements which are recognised in music but who show no decided leaning towards musical culture at all, and that through no fault of external circumstances. On the other hand, success in the sphere of practical music has been known to come to those who had a decided lack in the perception of one or more of the factors recognised in the psychology of hearing.

If it is required, therefore, to test for the presence of innate musical tendencies, entire isolation of constituent factors in music is not likely to be of great service, rather ought a factor which is considered sufficiently worthy of special attention, to be brought into prominence with a musical background, the conditions of the test being therefore analogous to those occurring in musical performances. The phrase [1] and memory [2] tests previously described afford examples of what is here meant.

Difficulties, however, are experienced in securing sufficient prominence to the particular point to be examined without either breaking completely away from a musical background or obscuring the main feature with a mass of other equally attractive material. On this score, objection might be raised to the cadence [3] test where the recognised musical endings are deliberately detached from their contexts. Actually, on testing children with examples in which cadences drawn from the works of the classical composers appeared in their original contexts, it was found that the results were so discordant that one could only conclude that the subjects had succumbed to the attractiveness of whole musical sentences and did not give judgments based on their appreciation of the various degrees of finality of the cadences employed.

Another reason why music tests should be constructed preferably from musical material is that it is desirable that such tests should appeal to teachers of music who, at a time

[1] *Brit. Journ. Psy.*, Vol. XVII, p. 115 (1926).
[2] *Loc. cit.*, Vol. XIX, p. 400 (1929).
[3] *Loc. cit.*, Vol. XVII, p. 112 (1926).

when the value of aural training has achieved universal recognition, would scarcely be expected to be interested in tests of isolated psycho-physical functions.

The cadence, phrase and memory tests previously described do not cover adequately all aspects of practical music, notable omissions being perception of accent and quality. Although it has been pointed out above that there is little to be gained in the study of musical capacity by considering in isolation the factors which form the basis of the psychology of hearing, yet there is no objection to considering any one factor in its relation to a passage of music. Accent, cadences and phrasing are sufficiently predominant in musical compositions to be treated as vital elements in a general structure, and may conveniently be taken as factors from which to frame a scheme of tests of musical capacity.

Three further tests of musical capacity are described below which are intended to accompany the cadence, phrase, and memory tests: viz. time, quality and creative tests.

II. Accent (or Time) Test.

"It is so evident as to be almost axiomatic, that *Accent* lies at the root of all intelligibility in music . . . the desire that the mind has for a certain element of unity in design has led those who have written music to maintain, for the most part, one distribution of accent throughout an entire composition, or at any rate through a large section of it."[1]

The place of accent in music is thus a very important one. Wherever appreciation of music exists, there must be an innate feeling for accent. Nevertheless, though it is practically impossible to sing or play a series of notes without laying more stress upon some than upon others, "musical" performances are not wanting which lack vitality because of the omission of *sustained* attention to appropriate accentuation. Class teachers in school know how difficult it is to get the pupils to be consistent in their placing of accents even in simple music. The least troublesome music perhaps in this connection is that of a martial character where no doubt the

[1] Macpherson, *Form in Music*, p. 5 (1908).

suggestion of regular movement is helpful in regulating the position of the accents. On carrying this relation between movement and accentuation to its logical conclusion, it is found that, in a singing class, children learn correct accentuation more quickly if they are allowed to beat time while they are singing, especially when they are told to emphasise the "down-beat."

It is necessary to draw attention here to the distinction between accentuation and rhythm, for both musicians and psychologists have frequently used the latter term in reference both to *time* and *accent*. To quote Macpherson [1] again: "The term Rhythm is one that is often used in a sense which at best may be described as somewhat loose as to its exact application. It is often confused with 'Time,' and one often hears such expressions as 3/4 Rhythm, Quadruple Rhythm and so on; or, as likely as not, it is regarded as synonymous with Accentuation, and the particular way in which notes are grouped between the successive strong pulses is often regarded as giving the *Rhythmic* shape and impulse. . . ."

"Rhythm, although it necessarily includes the two factors of Accent and Time, goes further than either, and demands for its expression and realisation the grouping of measures or bars into sets, these sets being defined, or marked off, by a species of musical punctuation which is the result of the employment of *Cadences*."

"Rhythm may be said to be the division of music into intelligible periods, which periods are largely determined by the occurrences of cadences."

Seashore has given what he calls a Rhythm Test among his Measures of Musical Talent—a series of gramophone records based on his book, *The Psychology of Musical Talent*. In this test fifty pairs of "rhythms" are sounded (like pencil tappings on a table top). The subjects are asked to state whether the second "rhythm" of a pair is the same as (S), or different from (D) the first. We may illustrate thus:—

(*a*) – –   – –   – – –,   – –   – – –   – – (D):
(*b*) – –   –   – – –,   – –   –   – – –   (S);

[1] *Loc. cit.*, p. 9, *et seq.*

where the lengths of the spaces between the dashes are suggestive of differences in time intervals between successive taps.

It might appear here, since each tap is of the same intensity as the others in the example, that the rhythm is quite independent of accent. Careful observation, however, shows that there is subjective accentuation owing to the fact that the intervals between the various taps are not equal. A tap sounded at a longer interval than usual after the preceding tap will appear to stand out as if accented.

FIG. 1.

The accent test now presented, in its original form, consisted of 25 examples; each example comprised a pair of musical phrases, the subjects being asked to record whether the second phrase was accented the same as (S), or differently from (D), the first. Specimen examples are shown in Fig. 1, in which the notes to be stressed are marked by a Sforzando sign (Λ). It will be seen that these stressed notes are always the first notes of the bars into which the music is divided; they occur at regular intervals of time as in musical compositions and the test might be called, not inappropriately, a *time test*, owing to its connection with what are known as duple, triple, quadruple, etc., " times " in music.

In order to make quite clear to the subjects that they were required to give their judgments with regard to accent, a demonstration was given on the piano indicating the accented notes in various phrases. The subjects were also allowed to beat time to short melodies played on the piano, emphasis being laid on the significance of the down-beats, the corresponding notes in the melodies being specially accented. The test was then given to the subjects, the examples being played on a piano.

At the first testing, a group of thirty-four elementary school girls, of ages 12-14 years, were examined. From the fact that twenty-six out of the thirty-four gave from 50 per cent. to 70 per cent. only of correct judgments and five girls obtained less than 50 per cent. correct, it was concluded that the test in its original form was too difficult since it did not offer sufficient latitude in the grades of difficulty of the examples. A further set of twenty-five examples of a simpler character but constructed on the same lines as previously described was, therefore, added to the first twenty-five examples but the results were even worse than before, seventeen out of thirty-six girls giving between 40 per cent. and 8 per cent. of correct judgments.

The fact that practically half the class obtained considerably *less than 50 per cent.* correct indicates the probability that there was a tendency to judge the opposite of what is correct in the various examples since, according to the laws of chance, a subject having no musical talent would be expected to obtain about 50 per cent. correct. Careful examination of the votes recorded for the individual examples showed that apparently the subjects were inclined to judge of degrees of floridness in the examples rather than of the modes of accentuation. Thus in Fig. 1 (*a*), although the two parts of the example are accented in the *same* manner, yet most of the subjects decided that this was a case of *difference*, no doubt because the second part is distinctly more "florid" than the first part. Conversely, as in Fig. 1 (*c*), where the accentuation is different but the floridness similar in each part, the answers were in accordance with degree of floridness.

Perhaps the addition to the length of the test and the

consequent increase in fatigue of listening were also partly responsible for the falling off in the results, and it was therefore quite clear that an entirely new test was required.

It should be noted that the results of this preliminary testing illustrate unambiguously the difficulty children experience with regard to accent, and they constitute a powerful argument in favour of retaining special "time" studies in the music classroom.

FIG. 2.

In view of the obvious difficulty of the original accent test, a new test was designed consisting of twenty-five examples of the type shown in Fig. 2, the subjects being asked to

record whether the second sentence in an example is the same as (S) or different from (D), the first in respect of accentuation. Some of the phrases in the new test are longer than those in the original test, though none exceed four bars in length. The increase in length is a guarantee that each part of an example shall last sufficiently long for the "lilt" to be prominent.

The general principle underlying the construction of the examples is *one note only to each beat of a bar*. Where deviations from this principle occur, those in one part of an example are matched as far as possible by similar deviations in the other part, e.g. Fig. 2, *c*, *d*.

The above simplification yielded a marked improvement in the results with the same class of girls (thirty-three present) the analysis being thus:

Number having 90 % to 100 % correct (highest mark 92 %)	4
,, ,, 80 % ,, 89 % ,,	11
,, ,, 70 % ,, 79 % ,,	9
,, ,, 60 % ,, 69 % ,,	7
,, ,, 50 % ,, 59 % ,,	2
	33

A casual inspection of this analysis would seem to suggest that guess-work had been reduced to a minimum in the recording of the votes, since all the subjects obtained considerably more than half marks. The class music teacher expressed the opinion that the girls who had obtained the highest marks were undoubtedly the "most musical" in the class, judged according to their performance in singing lessons.

A further twenty-five examples modelled on the lines of the first twenty-five, were now added, and the complete test of fifty examples was employed in studying correlations with the previously described tests, viz. cadence, phrase and memory tests. It is worthy of mention that the accent test, consisting of fifty examples, did not prove too long when given to elementary school children of ages 12-14 years, and, moreover, it aroused the interest of the children to such an extent that they welcomed a repetition at an early date. This latter question of interest is of course an important one

if tests are to be at all successful, especially when children are concerned.

III. Reliabilities and Correlations.

The evolution of the accent test has been fully described above and the development of the cadence, phrase and memory tests has been previously given elsewhere.[1] The immediate aim was to obtain a selection of examples in each test which would give a suitable distribution of marks when applied to children, such as those usually found in the higher classes of the average elementary school, that is, examples had to be found which would cover all degrees of difficulty from very easy to difficult. Suitable examples could only be framed after considerable preliminary testing as outlined above in connection with the accent test.

A satisfactory collection of examples for each test having been arrived at as regards distributions of marks, the next step consists in examining the reliabilities of the tests. Each test ought plainly to give practically the same results with a given group of subjects on different occasions.

For the general study of musical ability it is also important to find the inter-correlations between the various tests.

(*a*) *Reliabilities.*

The accent test was given on two alternate days to thirty-three elementary school girls of average age 12½ years, and Spearman's corrected "footrule" formula was applied to the results in order to determine the coefficient of reliability, (r). As the cadence, phrase and memory tests were also given in the same way the various reliability coefficients for all four tests are recorded here :—

Accent test :	$r = 0{\cdot}73$
Cadence ,,	$r = 0{\cdot}91$
Phrase ,,	$r = 0{\cdot}71$
Memory ,,	$r = 0{\cdot}75$

[1] *Brit. Journ. Psy., loc. cit.*

Further testing for reliability coefficients was carried out with 114 boys and girls (fifty-eight boys, fifty-six girls) of average age 13 years, with the following results :—

Accent test :	$r = 0{\cdot}78$
Cadence ,,	$r = 0{\cdot}90$
Phrase ,,	$r = 0{\cdot}73$
Memory ,,	$r = 0{\cdot}80$

These figures obviously indicate a high degree of reliability.

(*b*) *Correlations.*

Considerable testing has been carried out for the purpose of determining the inter-correlations of the tests, and at first somewhat erratic variations in the coefficients of correlation were obtained which have been traced to such factors as the use of a piano of uneven action, distracting noises outside the room, and inexperience of the children in committing answers to paper. This latter occurred only where the children were between 10 and 12 years of age. Subsequent examination of 114 boys and girls of average age 13 years under good conditions (viz. in a quiet hall with a grand piano) yielded the following coefficients of correlation (a = accent, c = cadence, p = phrase, m = memory test) :—

	am.	*ac.*	*ap.*	*cp.*	*mp.*	*cm.*
First testing :	0·45	0·35	0·29	0·22	0·40	0·47
Second ,,	0·42	0·37	0·26	0·19	0·38	0·46

These coefficients appear to be somewhat low, but this may perhaps be expected in some cases, particularly where the phrase test is involved, for musical writers and teachers are inclined to look upon perception of good phrasing as a quality frequently lacking in even highly accomplished musicians.

It is interesting to notice the way in which the accent, cadence, phrase and memory tests correlate with *general intelligence*. In order to investigate this point, fifty children were given the four music tests and also the Tomlinson "West Riding" Tests of mental ability, Set Y. Denoting "intelli-

gence" by *i*, the coefficients of correlation worked out as follows :—

ai.	*mi.*	*ci.*	*pi.*
0·48	0·51	0·38	0·15

Using these results together with the inter-correlations for the various tests given above, in order to eliminate the "intelligence" factor, the following coefficients are obtained :—

$$r_{ac.i} = 0{\cdot}37$$
$$r_{ap.i} = 0{\cdot}25$$
$$r_{cp.i} = 0{\cdot}20$$
$$r_{mp.i} = 0{\cdot}38$$
$$r_{cm.i} = 0{\cdot}40$$
$$r_{am.i} = 0{\cdot}24$$

(where $r_{ac.i}$ indicates the correlation between the accent and cadence test, "intelligence" being eliminated, etc.). Since these coefficients are all positive and significant it is clear that there is some factor involved which is common to all four tests. This may, for the present, be designated "musicality." For the further study of this factor obviously extended testing on the above lines must be carried out. It seems clear that general intelligence does play a considerable part in the formation of the judgments in connection with the accent, cadence, and memory tests. The low correlation between the phrase and intelligence tests appears to support the view expressed by musical writers from general observations that good phrasing in musical performances is not always obtained even from expert musicians, though where it is present, it stamps the hall-mark of the real artist.

IV. Quality Test.

Since the various musical instruments differ from one another in the quality of the tones they produce, *quality* appears to be a possible factor as the basis of a test of musical capacity ; thus the careful listener to an orchestral performance is able to pick out the tones of the different instruments employed, and the ability to do this is at least a test of his capacity of attending to musical sounds.

For the purpose of the present test, five easily distinguished tone qualities were employed produced from the following instruments: piano, violin, clarinet, cornet and flute. Prior to the carrying out of a testing, the children (average age 12½ years) were carefully drilled in the recognition of the tones, and finally all could give correct answers to twenty-five examples on the identification of the individual tones when the instrumentalists were behind a screen. This preliminary

FIG. 3.

drill is of course essential, since otherwise it is possible for the children to recognise differences in quality without being able to name the instruments concerned.

The test proper commenced with the playing of two of the five instruments according to such examples as those shown in Fig. 3. The children were at first asked to name the instrument playing the lower of two parts and record thus: P (piano), Co (cornet), Cl (clarinet), V (violin) or F

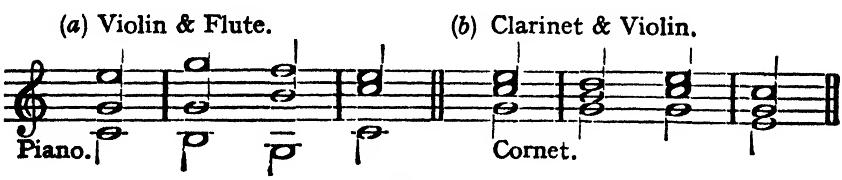


FIG. 4.

(flute). On testing with twenty-five examples, it was found that this was much too difficult, since only three out of twenty children secured more than 60 per cent. of the marks. Much better results were obtained when the children were asked to identify the instrument playing the upper of the two parts. In this case thirteen out of twenty children secured 60 per cent. of the marks, the highest mark being 95 per cent.

Further experimenting with short three-part phrases, Fig. 4, showed again that the recognition of the instrument

playing the lower part was difficult, the recognition of the instrument playing the *middle* part almost impossible, and the recognition of the instrument playing the *upper* part fairly easy, though the results were not quite as good as in the two-part examples, nine only of the children securing over 60 per cent. of the marks, with the highest mark 80 per cent.

The general conclusion from the preliminary application is that this test is suitable for examination of the ability to listen, and this is of course an important matter for a musician.

Owing to the inconvenience of securing five instrumentalists for the carrying out of applications of this test, further work is postponed till suitable gramophone records have been prepared.

V. Creative Test.

The chief difficulty in drawing up a scheme of tests of musical ability is that of obtaining an outside criterion of musicality. Several investigators have evaded the difficulty by taking arbitrarily one of their own tests as standard, and no one has previously faced the question squarely and indicated a solution.

The test, *par excellence*, of musical capacity is that of the ability to create music, thus the biographers of the prodigy, Mozart, delight in recounting the tales of the way in which he composed sonatas at the age of three. A *direct* creative test is of course almost impracticable if a class of children is to be examined as to their possession of musical talent, but there appear to be decided possibilities in an indirect test of creative ability modelled on the lines of the following.

The test consists of fifty examples, in each of which a short musical phrase is presented. This phrase is followed by a second phrase which may, or may not, be a suitable melodic continuation of the first phrase, and the subjects are asked to vote according to whether or not they consider the sequence satisfactory (Y = yes, N = no). An appropriate demonstration is given before the test begins.

Experience shows that with children of 12-14 years of age it is necessary, in the cases where the second phrase does not form a suitable sequence to the first, to make a most

marked difference in the two phrases presented, even to the extent of putting the second phrase in another key, or after a different time-signature from the first. Specimen examples as employed in the present test are shown in Fig. 5.

FIG. 5.

Fifty children have been tested and gave the following distribution :—

Number having	90 % to 100 %	correct (highest mark 91 %)	1
,, ,,	80 % ,, 89 %	,,	12
,, ,,	70 % ,, 79 %	,,	18
,, ,,	60 % ,, 69 %	,,	9
,, ,,	50 % ,, 59 %	,,	8
,, ,,	less than 50 % ,,		2
			50

Opportunity for giving this test along with the other tests has not so far presented itself, but it is hoped to have gramophone records made of all the tests so that examination of large numbers of subjects may be undertaken.

VI. CONCLUSION.

Up to the present stage of investigation, the author has been satisfied if he could pick out, by means of the tests mentioned, the best half-dozen pupils in the classes which were tested, the class music teacher's experience being drawn upon for a standard of comparison. It is gratifying to note that this could be done.

It may be asked why the practice of Seashore, Revesz, Stumpf, Pear and others was not followed in asking the pupils who were tested such questions as whether they liked to hear music, whether they were fond of concerts, whether they liked singing, etc. The reply is that such information as is obtained in this manner is usually untrustworthy and of no direct use. Its lack of definite quantitative value (apart from its unreliability) is sufficient to make it useless as an external criterion of musicality for which purposes such information is presumably required. Seashore, for example, made no use of the replies to his questions, and merely remarks that questions of the kind instanced above were asked of his subjects and the replies are on file for interested persons to examine.

VII. Summary.

1. Reference is made to the necessity, as pointed out in previous papers, of constructing tests of musical capacity from musical material.
2. Three new tests for the estimation of musical capacity are described, viz. accent, quality and creative tests. Some preliminary results of the application of these tests to children of 12-14 years of age are given.
3. Reliability and correlation coefficients are recorded for some applications of the accent test, together with the previously described cadence, phrase and memory tests.

VIII. Acknowledgments.

Thanks are due to Dr. Ll. Wynn Jones, Department of Experimental Education, Leeds University, for his advice and encouragement in the work. Also to Miss Stainton (Blenheim Girls' School, Leeds), Mr. L. G. Thornber (Director of Education, Huddersfield), and Mr. J. Crosland (Spring Grove Council School, Huddersfield), for facilities in giving some of the tests.

VII.—Condenser Resistance Measurement by use of a Variable Mutual Inductance.

By W. Jackson, M.Sc.

Introduction.

Considerable attention has been devoted during recent years to the measurement of air condenser resistance at radio frequencies, and the usual procedure has been to base the measurement on the assumption of zero loss in some particular standard air condenser with which the test condenser is compared. Dr. Dye [1] has developed a special condenser capable of providing three capacity values, the use of which as a standard rests on the assumption that the whole of its losses are concentrated in the small quartz pillars supporting the insulated plate. In a method developed by R. M. Wilmotte,[2] the measurement is made by substituting for the test condenser an air condenser, assumed to be perfect, and a series resistance, the latter serving to bring the current in the measuring circuit to the same value in the two cases. A continuously variable air condenser, for which this supposition of zero loss is justified, is not, however, normally available in a laboratory, so that the general use of comparison methods is likely to be attended with uncertain accuracy.

In a paper [3] dealing with a method of coil resistance measurement at high frequencies by use of a variable mutual inductance, the author outlined the application of a modified form of circuit, in which a standard condenser is not required, to the direct measurement of condenser resistance. The present paper deals with the development of this method.

The early part of the paper discusses the theory of the method and the errors which result from the small self capacities inherent in the mutual inductance, and is followed

by a statement of the results obtained in measurements on a laboratory variable air condenser. The subsequent part deals with the experimental procedure adopted in providing a check on these measurements. This consisted in an independent determination of the resistance of the primary coil of the mutual by the method of the previous paper, followed by measurement of the combined resistance of this coil and the condenser by the "Resistance Variation"[4] method. From these results the condenser resistance was estimated by subtraction.

In addition, during the independent measurement of the condenser and coil resistances, the theory of the respective methods was checked by noting the effect of increasing artificially the various self capacities associated with the mutual inductance.

CONDENSER RESISTANCE MEASUREMENT.

In the simple circuit of Fig. 1, C, the condenser of which the resistance *r* is to be measured, is connected in series with

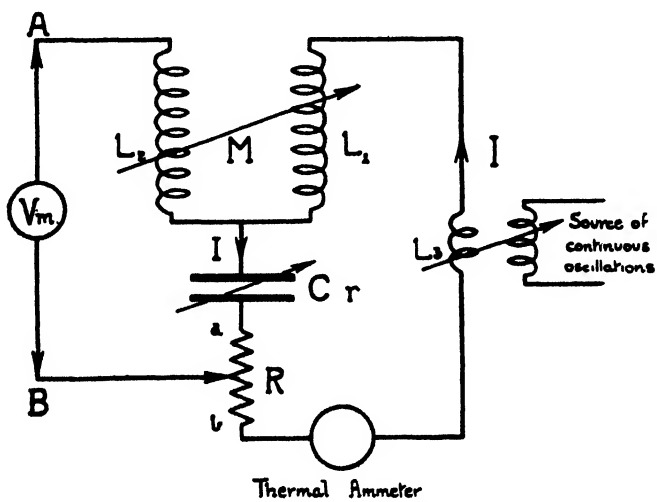


FIG. 1.

the primary coil L_1 of the variable mutual inductance to form a resonant circuit, loosely coupled to a source of continuous

oscillations of high frequency $\frac{\omega}{2\pi}$ by means of the small coil L_3. The secondary coil L_2 of the mutual is joined at one end to the common point of L_1 and C, and at the other to one terminal A of a thermionic voltmeter. The other voltmeter terminal B is taken to the variable tapping point on a non-inductive potentiometer resistance R connected in series with the L_1CL_3 circuit.

For a current I, caused to circulate round the circuit L_1CL_3 by tuning to the oscillator frequency, and for a voltmeter of infinite input resistance, the voltage between the points A and B, with the potentiometer tap at "*a*", may be written

$$V = I\left\{r + j\left(M\omega - \frac{1}{C\omega}\right)\right\}.$$

As M is varied the voltage V passes through a minimum value V_1 for $M = \frac{1}{C\omega^2}$, when

$$V_1 = Ir \quad . \quad . \quad . \quad . \quad (1)$$

For this value of M the insertion of a known pure resistance R between the points "*a*" and B increases the voltmeter reading to V_2, where

$$V_2 = I(r + R) \quad . \quad . \quad . \quad (2)$$

The unknown condenser resistance r may be determined directly from equations (1) and (2), but more accurately from a curve connecting V and R obtained by varying R through a series of values. This curve should be an exact straight line which, when produced backwards, should cut the horizontal axis of R to the left of the origin. The value of this intercept gives the resistance of the condenser C.

This simple expression for minimum voltage is, however, modified by the presence of resistance and self-capacity in the coils L_1 and L_2 of the mutual, and by the mutual capacity between them. Representing the resistances and self-capacities of L_1 and L_2 by R_1, R_2 and C_1, C_2 respectively, and their mutual capacity by C_{12}, reference to a paper by Butterworth [5]

on the capacity errors in standard mutuals shows that the voltage across the secondary coil is given by

$$V_s = I(\sigma + jM'\omega)$$

where M' is the effective mutual inductance between L_1 and L_2 and is of the form

$$M' = M + C_{12}R_1R_2 + \omega^2\{C_1L_1M + C_2L_2M - C_{12}(L_1 - M)(L_2 - M)\},$$

and σ is an impurity for which the self and mutual capacities are responsible and is

$$\sigma = \omega^2\{C_1R_1M + C_2R_2M - C_{12}[R_1(L_2 - M) + R_2(L_1 - M)]\}.$$

The general expression for the voltage between the terminals A and B of the voltmeter is therefore

$$\begin{aligned} V &= I\left\{(r + \sigma) + j\left(M'\omega - \frac{1}{C\omega}\right)\right\} \\ &= I\{a + jb\} \qquad . \quad . \quad . \quad . \quad . \qquad (3) \end{aligned}$$

The voltage indicated on a voltmeter of infinite input resistance is then

$$V = I\sqrt{a^2 + b^2}$$

which will be a minimum with respect to variations in M when

$$\frac{d}{dM}(a^2 + b^2) = 0.$$

With reasonable assumptions regarding the order of magnitude of the quantities involved, it is shown in the appendix that the value of M giving minimum voltage is given by

$$M = \frac{1}{C\omega^2}\{1 - \omega^2L_1C_1 - \omega^2L_2C_2\} \qquad . \quad . \qquad (4)$$

for which value of M the recorded voltage is

$$V_{min.} = \left\{\begin{array}{l} r + \frac{1}{C}[C_1R_1 + C_2R_2 + C_{12}(R_1 + R_2)] \\ \quad - \omega^2C_{12}(R_1L_2 + R_2L_1) \end{array}\right\} \qquad . \qquad (5)$$

The primary and secondary coil self-capacities lead, therefore, to an apparent condenser resistance in excess of the actual, while the effect of the mutual capacity may be

to increase or decrease, but generally to decrease, this value depending on the magnitude of the constants of the mutual. The accuracy with which r can be determined depends on the extent to which these capacity errors can be kept small in the design of the mutual.

The value chosen for the inductance L_1 of the primary coil of the mutual is bound up with the size of the test condenser C and the frequency, or wavelength, range over which measurements are to be carried out, since it must be possible to adjust the circuit L_1CL_3 to resonance at all desired frequencies in this range. This resonant condition is specified because of the need to obtain large current values in the measuring circuit for accurate recording of the required minimum voltage, and at the same time to ensure as much freedom from harmonics as possible in the working current.[6] This current must further be provided with a small coupling coil L_3, if similar settings of the mutual are to serve for the provision of minimum voltmeter reading in the independent measurement at the same frequency of both condenser and primary coil resistance. The respective values of M in the two cases are given approximately by $1/C\omega^2$ and L_1,[3] values which approach equality at resonance of the L_1CL_3 circuit as L_3 is made small compared with L_1.

The secondary coil inductance must now be chosen so that, when coupled to L_1, it can be arranged to give a mutual inductance M somewhat in excess of L_1. The value of L_2 is, therefore, dependent on the chosen value for L_1 and on the manner of coupling the two coils. Equation (5) brings out the need for keeping the coil self capacities C_1 and C_2, and the mutual capacity C_{12}, small, so that single layer construction and end-to-end coaxial location of L_1 and L_2 is desirable. With this arrangement L_2 is, of necessity, much larger than L_1 for the provision of the required value of mutual inductance. In winding the coils it is also important to ensure that their high frequency resistances, R_1 and R_2, shall be small, a consideration which also makes single layer construction important.

The details of the mutual inductance finally adopted for the purpose of making measurements on a laboratory variable

air condenser of maximum capacity 2000 micro-microfarads in the region of 1000 metres wavelength were as given in the following table. Both the primary and secondary coils were wound single layer on cylindrical paxolin former using silk covered wire. The effect of silk covering and the use of paxolin former on the high frequency resistance of such coils had been found previously to be small.[7] The primary coil was fixed on the base of the mutual, and the secondary arranged for relative coaxial movement under coarse and vernier control. The latter is essential in order that there may be no difficulty in adjustment for minimum voltmeter reading. The vernier control was made remote so as to ensure freedom from hand capacity effects. In order to reduce the mutual capacity between the coils, the common point was obtained by joining their adjacent ends.

	Primary Coil.	Secondary Coil.
Turns.	29	120
Wire Diameter .	0·045 cm.	0·045 cm.
Coil diameter .	6·0 ins.	6·0 ins.
D.C. resistance .	1·45 ohms.	5·70 ohms.
True inductance .	$L_1 = 244$ microhenrys	$L_2 = 2700$ microhenrys
Self capacity .	By direct measurement $C_1 = 4{\cdot}2\ \mu.\mu.f.$	Natural wavelength when erected on base of mutual = 296 metres $C_2 = 9{\cdot}1\ \mu.\mu.f.$

Without introducing the complication of a calibrated amplifier, a thermionic voltmeter fulfilling the requirement of infinite input resistance does not lend itself to the accurate measurement of voltages of less than about 0·5 volt. For measurement of a condenser resistance of the order of 1·0 ohm, therefore, working currents up to 1·0 ampere become necessary. The generation of high frequency currents of this order does not offer any difficulty with the valve oscillator. Complete screening of the oscillator is essential, however, to ensure freedom from direct voltage injection into either the secondary coil of the mutual or the voltmeter circuit. As a further precaution the thermionic voltmeter was also screened, and its valve de-capped with a view to reducing its input circuit capacity.

Since the voltage across the condenser C is many times greater than the phase component of voltage to be measured as its resistance drop, care is necessary in adjusting the circuit conditions for measurement, if damage to the voltmeter is to be avoided. For example, should the condenser C have a power factor of 1×10^{-3}, the total voltage across C is 1000 times the voltage to be measured, so that slightly incorrect adjustment of the mutual, when the measuring circuit is carrying currents of the order of 0·5 ampere, is sufficient to cause the voltmeter scale to be exceeded. The

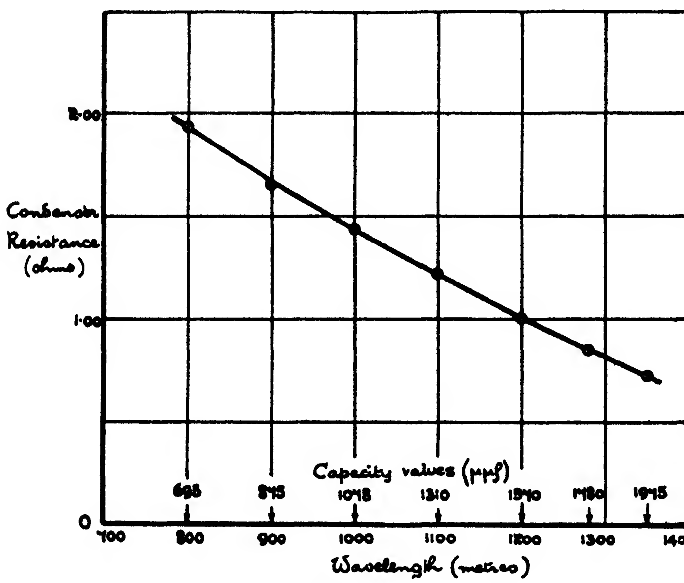


FIG. 2.

procedure adopted was to commence with very weak coupling of L_3 to the oscillator and to tune the L_1CL_3 circuit on C to the desired wavelength with the voltmeter inoperative. This was possible with circulating currents of only a few milliamperes since the thermal ammeter in use was multirange. On introducing the voltmeter an approach to the final adjustment of the mutual was possible without danger to the voltmeter. The desired working current and the final mutual setting were then attained by successively increasing the coupling of L_3 to the oscillator and appropriately readjusting M.

The results of a series of measurements taken over a wavelength range of 800 to 1350 metres are given in Fig. 2, and the condenser power factor calculated therefrom in Fig. 3, to which further reference is made later.

It has been shown that the resistance values of Fig. 2 are subject to an error which can be estimated from the known constants of the mutual by use of equation (5). Taking for R_1 and R_2 the calculated high frequency resistances[8] of the primary and secondary coils, a procedure which is justified by the subsequent measurements, the effect of the self capacities C_1 and C_2 on the apparent condenser resistance at 1100 metres

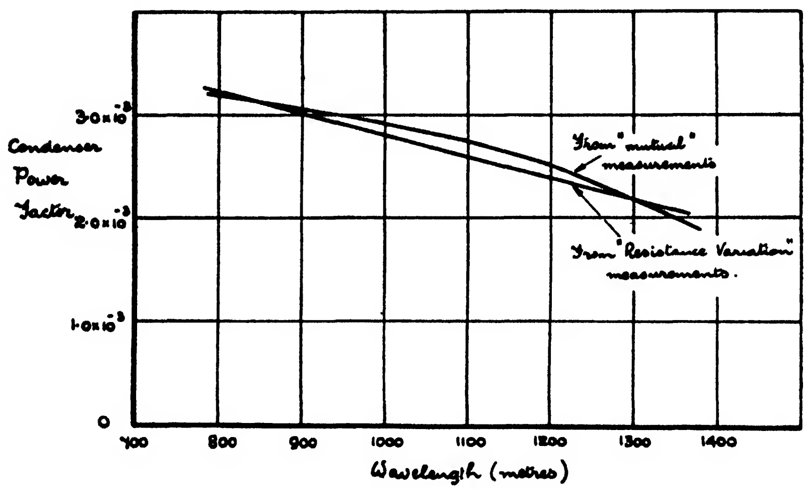


FIG. 3.

is given by calculation from this equation as an increase of 0·096 ohm. A reliable measurement of the mutual capacity C_{12} is not possible, but this may be taken as small, since, at the setting for minimum voltmeter reading, the adjacent ends of L_1 and L_2 were more than 1·0 cm. apart. As the calculated decrease in apparent resistance per micro-microfarad of C_{12} is 0·016 ohm, the net error as calculated is not likely to be in excess of 0·05 ohm, which, with the condenser under test, corresponds to an apparent resistance 4 per cent. high.

The effects on the apparent condenser resistance at 1100 metres of artificial increase of the self and mutual capacities in turn are shown in Fig. 4, and are of interest in view of

the mathematical expectations. It is seen that the nature of the effects is as predicted, although the measured change resulting from large variation of C_2 is somewhat greater than that expected.

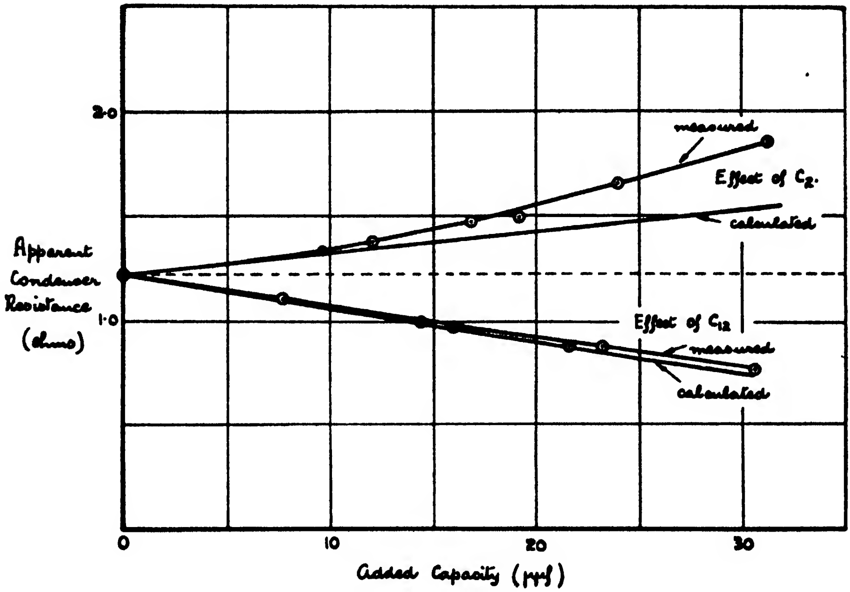


FIG. 4.

PRIMARY COIL RESISTANCE MEASUREMENT.

The method adopted for measurement of the primary coil resistance R_1 was essentially that developed in the previous paper,[3] and required modification of the circuit of Fig. 1 to that of Fig. 5. The method consists in the measurement of the phase component of voltage across the primary coil following neutralisation of the quadrature component by appropriate adjustment of the mutual inductance M. As the mutual inductance between L_1 and L_2 is varied, the voltmeter reading passes through a minimum value for

$$M = L_1(1 + L_1C_2\omega^2 - L_2C_2\omega^2). \quad ^3$$

For an ideal mutual, devoid of secondary coil resistance and self capacities, this minimum voltage gives a measure of the primary coil resistance in the form

$$V_{\text{min.}} = IR_1.$$

When, however, these quantities are taken into account the resistance value provided is an apparent primary resistance.

$$R^1 = R_1 \{1 + L_1C_1\omega^2 - \frac{R_2}{R_1} . L_1C_2\omega^2 + (L_2 - L_1)C_{12}\omega^2\} \quad (6)$$ [3]

from which it is seen that C_1 and C_{12} are responsible for positive, and C_2 for a negative, error in the deduced resistance R_1. Observance of the precautions previously discussed in connection with the construction of the mutual serve to keep these errors of small relative magnitude.

The results of a series of measurements over the same

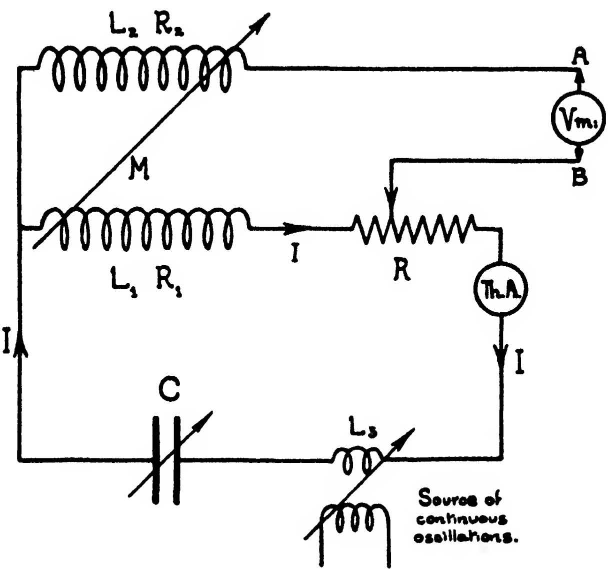


FIG. 5.

wavelength range as before are recorded in Fig. 6, along with the curve of calculated coil resistance as derived from Butterworth's theoretical formula.[8] Definite agreement occurs between the measured and calculated curves, and it is of interest to analyse the difference to determine whether it can be accounted for by the errors resulting from impurity in the mutual.

In this case it is possible to determine the mutual capacity C_{12} with reasonable accuracy. In the circuit of Fig. 5, the thermionic voltmeter is connected virtually across the outer

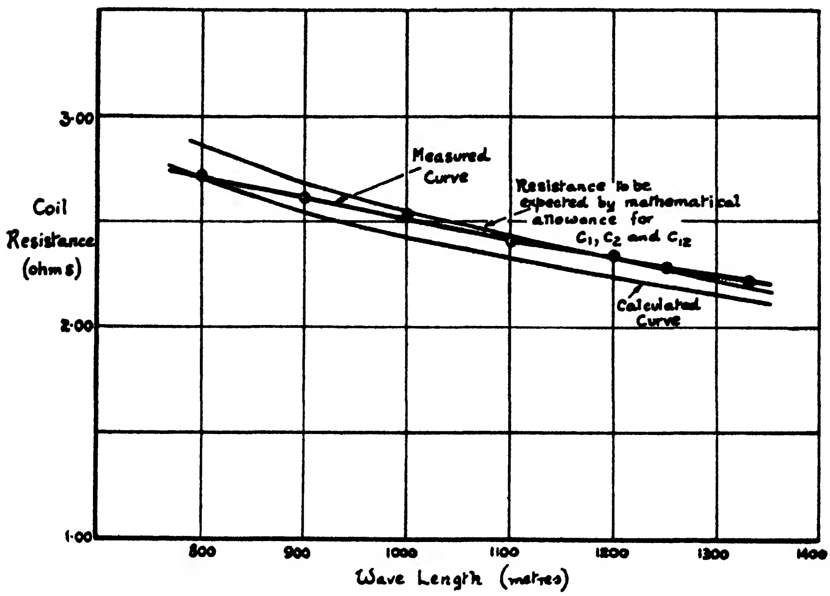

3·00
2·00
1·00
Coil Resistance (ohms)
Measured Curve
Resistance to be expected by mathematical allowance for C_1, C_2 and C_{12}
Calculated Curve
800
900
1000
1100
1200
1300
1400
Wave Length (metres)

FIG. 6.

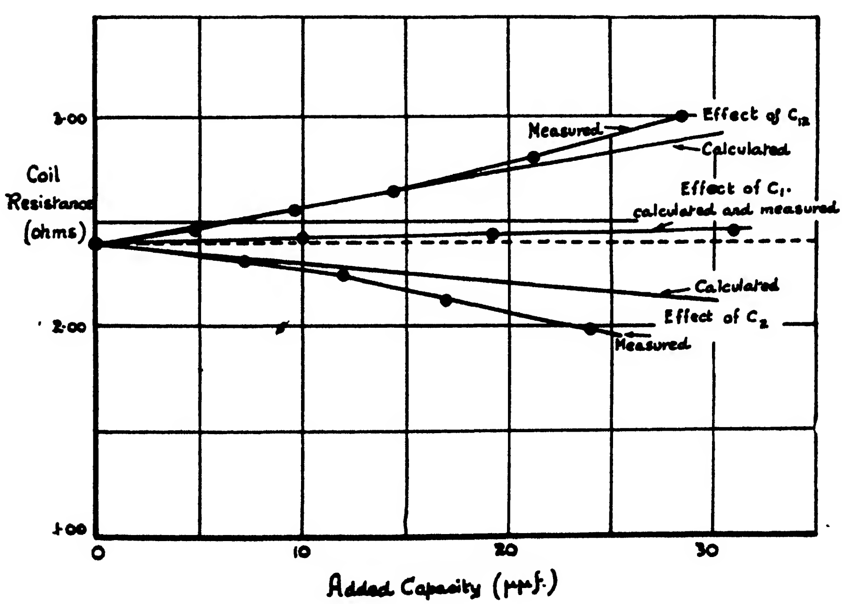

3·00
2·00
1·00
Coil Resistance (ohms)
Effect of C_{12}
Measured
Calculated
Effect of C_1. calculated and measured
Calculated
Effect of C_2
Measured
0
10
20
30
Added Capacity (μμf.)

FIG. 7.

ends of the primary and secondary coils of the mutual, so that C_{12} may be taken as the capacity of the input circuit of the voltmeter. With the voltmeter valve de-capped, this was measured under operating conditions of the voltmeter as 10·8 micro-microfarads. Using the calculated high frequency values of R_1 and R_2, the error due to self and mutual capacities can be calculated from equation (6), and provides the curve of R_1' in Fig. 6. The agreement with the measured values is now more marked except at the lower wavelengths, where the effect of C_2 in decreasing the apparent resistance appears more pronounced than has been estimated.

The results showing the effect on the primary coil resistance of artificially increasing the self and mutual capacities in turn appear in Fig. 7, where it is seen that the effect of C_1 and C_{12} in increasing, and of C_2 in decreasing, the apparent resistance is as indicated by equation (6).

"RESISTANCE VARIATION" MEASUREMENTS.

The primary coil of the mutual and the test condenser were finally associated, and their combined resistance measured by the "resistance-variation" method over the same wavelength range. The results are shown in Fig. 8 along with a curve representing the calculated primary coil resistance. Since this latter has been found to represent a close approach to the true resistance of the coil, the difference between the two curves may be taken as a measure of the condenser loss resistance. Due to the absence in these measurements of the coupling coil L_3 present in the resonant circuit of the mutual method, the condenser settings at a given frequency of measurement were slightly different in the two cases, but have been recorded in the corresponding resistance-wavelength curves. The condenser power factor as calculated from the above results is plotted in Fig. 3, where it is seen that good agreement occurs between the values as determined by the two methods of measurement, the difference over the frequency range concerned being never in excess of 6 per cent.

In drawing conclusions from this agreement as to the utility of the mutual method of condenser resistance measurement,

it should be remembered that the resistance values provided are virtually the sum of the condenser resistance desired and the impurity in the mutual. The accuracy obtainable in a measurement of the former depends, therefore, on the relative magnitude of the latter. Since small self and mutual capacities are inherently present in a mutual inductance, the method will always require very careful experimental development, and offer increasing difficulty with increase in frequency and when accurate measurements are attempted on condensers of very low power factor. Although theoretically the in-

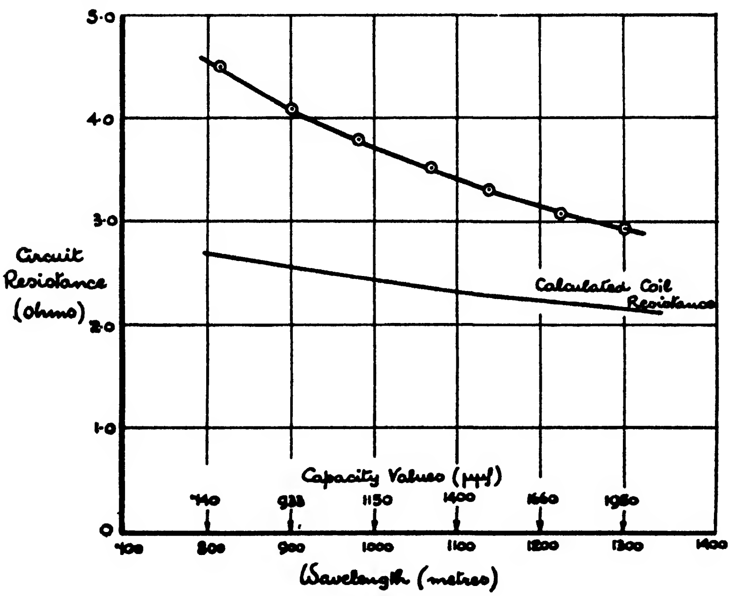


FIG. 8.

dividual components of the impurity error may be made self eliminating by artificial increase of the mutual capacity C_{12}, this adjustment is not of practical convenience over a range of frequency, since variation of the coil resistances with frequency would demand a variable correction.

The author's thanks are due to the authorities of the College of Technology, Manchester, for the facilities provided in the Electrical Engineering department for the carrying out of the recorded work, and to Professor Miles Walker for his constant encouragement.

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[3] *Journ. Inst. of Electrical Engs.*, p. 296, Vol. 68, 1930.
[4] *Radio Frequency Measurements*, Moullin, 2nd Edn., p. 263.
[5] *Proc. Physical Society*, Vol. 33, 1921.
[6] *Radio Frequency Measurements*, Moullin, 2nd Edn., p. 318.
[7] *Wireless Engineer*, May, 1928.
[8] *Phil. Trans. Royal Society*, Vol. 122, 1921 A.

APPENDIX.

The general expression for the voltage between the points A and B of Fig. 1 is

$$V' = I(a + jb)$$

where

$$\begin{aligned} a &= r + \omega^2\{C_1R_1M + C_2R_2M - C_{12}[R_1(L_2 - M) + R_2(L_1 - M)]\} \\ &= \{r - \omega^2 C_{12}(R_1L_2 + R_2L_1)\} + M\{\omega^2[C_1R_1 + C_2R_2 \\ &\qquad + C_{12}(R_1 + R_2)]\} \\ &= \alpha + M\beta \end{aligned}$$

and

$$\begin{aligned} b &= -\frac{1}{C\omega} + \omega\{M + C_{12}R_1R_2 + \omega^2[C_1L_1M + C_2L_2M \\ &\qquad - C_{12}(L_1 - M)(L_2 - M)]\} \\ &= -\frac{1}{C\omega} + \omega\{M + C_{12}R_1R_2 + \omega^2(C_1L_1M + C_2L_2M)\} \end{aligned}$$

since $M \doteqdot L_1$ for a small coupling coil L_3, at the setting for measurement, so that $C_{12}(L_1 - M)(L_2 - M)$ is a small quantity in comparison with both C_1L_1M and C_2L_2M.

$$\begin{aligned} &= \{-\frac{1}{C\omega} + \omega C_{12}R_1R_2\} + M\{\omega[1 + \omega^2L_1C_1 + \omega^2L_2C_2]\} \\ &= \eta + M\gamma \end{aligned}$$

The value of M for minimum voltmeter reading occurs when $\frac{d}{dM}(a^2 + b^2)$ is zero, when M is given by

$$M = -\frac{\alpha\beta + \eta\gamma}{\beta^2 + \gamma^2}.$$

Bearing in mind the order of magnitude of the quantities involved, and neglecting second order small quantities, the required value of M is

$$\begin{aligned} M &= \frac{\frac{1}{C\omega^2}\{1 + \omega^2L_1C_1 + \omega^2L_2C_2\}}{\{1 + 2\omega^2L_1C_1 + 2\omega^2L_2C_2\}} \\ &= \frac{1}{C\omega^2}\{1 - \omega^2L_1C_1 - \omega^2L_2C_2\} \end{aligned}$$

which also represents the condition that the reactive component b of the voltage is zero.

The required minimum voltage is therefore obtained by substituting this value of M in the real part a. Neglecting components of the second order of small quantities

$$\frac{V_{\text{min.}}}{I} = r + \frac{1}{C}\{C_1R_1 + C_2R_2 + C_{12}(R_1 + R_2)\}$$
$$- \omega^2 C_{12}(R_1L_2 + R_2L_1).$$

VIII.—Some Chromosome Numbers in British Species of *Rubus*.

By Mrs. Sarojini Datta, M.A. (*Calcutta*), M.Sc. (*Manchester*).

The extreme difficulty of obtaining any satisfactory taxonomic system for the large and polymorphic genus *Rubus* is a fact familiar to field botanists. For this reason the important results obtained by application of cytological and genetical methods in the allied genus *Rosa* have suggested to several workers the desirability of approaching the *Rubus* problem in the same way.

On the cytological side the most extensive work is that of Longley (1924). In the American species available to him a basic chromosome number of 7 is reported, polyploidy is found to be rife and to be associated with various degrees of disturbance in chromosome behaviour at meiosis. Conclusions are drawn both as to the delimitation of "true species" and with regard to the influence of hybridity in establishing the polymorphism of the American *Rubi*. The value of the method seems, therefore, to have been demonstrated.

Comparable data for European species are not available, though a beginning has been made by Crane and Darlington (1927). The opportunity afforded by the presence of a specialist on the systematics of the genus, Professor Lapworth of this University, was therefore welcomed. The observations to be recorded have been made incidentally to other work during a limited period as a research student in England. The field concerned is, however, so wide that even a small contribution may be of some value.

Methods.

Stolons were removed from branches identified in the field in the neighbourhood of Manchester by Professor

Lapworth during the summer and autumn of 1931. They were grown in pans of soil in a cool greenhouse during the following winter and those which survived have since been transferred to Manchester University Experimental Ground, where they are to be maintained in cultivation. Repeated attempts to propagate from branches by means of cuttings were unsuccessful.

Chromosome counts were made from root tips produced by the stolons and fixed in the chrom-acetic-formalin of Navashin (cf. La Cour, 1931). They were cut at 6μ and stained in gentian violet. Drawings were made at a magnification of $\times$ 2600 with a $\frac{1}{12}$-inch oil immersion objective of aperture 1·3 and an 18 Zeiss compensating occular with the aid of a camera lucida; reduction by $\frac{1}{4}$ brings the actual magnification of the text figure to $\times$ 1950.

A herbarium specimen of the identical branch used was kept in every instance. These have been deposited in the Herbarium of Manchester University and access to them may be had on application to the Curator.

The nomenclature used is that of Moyle Rogers, except in one instance (see footnote 3).

RESULTS.

Chromosome counts have been obtained in ten species. Three of these to some extent overlap, but confirm, the results of other writers. Only one additional species is known to have been reported elsewhere (*R. thyrsiger* by Crane and Darlington). This is included in the list below. These eleven species, though only a fraction of the total number of British forms, nevertheless represent seven out of the fourteen recorded sections of the genus.

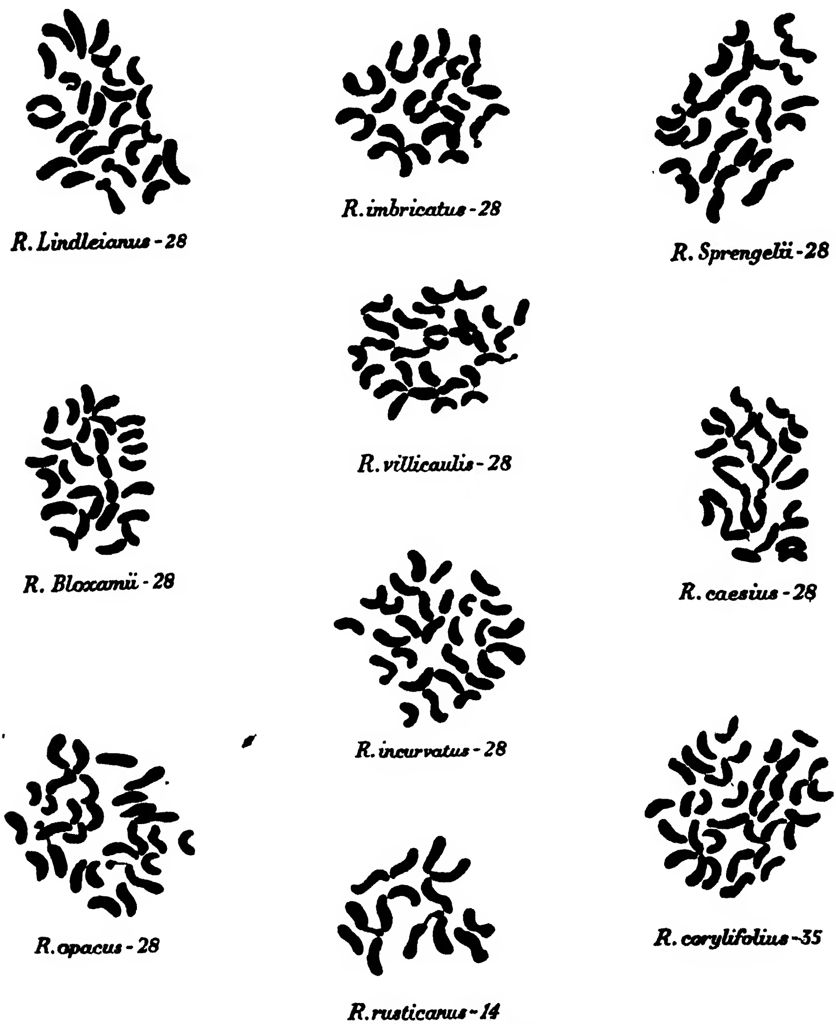
All the species are polyploid in various degrees on the same fundamental number, 7, reported by Longley and already confirmed by Crane and Darlington. Only one, *R. rusticanus*, is diploid, one, *R. corylifolius*, is pentaploid, while all the others are tetraploid in their somatic cells.

The pentaploid state of the representative of the admittedly collective[1] species, *R. corylifolius*, is of interest in

[1] Cf. Moyle Rogers, *loc. cit.*, p. 566.

view of the tetraploid state of the representative available to Longley. The homology of the two may be questioned. In any case the British form can hardly be other than of hybrid origin.

Unfortunately none of the plants used has been in cultivation long enough to have flowered. Evidence of hybridity from meiotic aberrations in the tetraploid species has therefore not been obtained.



Somatic chromosomes in species of *Rubus*, magnified × 1950.

SOMATIC CHROMOSOMES OF BRITISH RUBI.

(*Systematic arrangement according to Moyle Rogers.*)

	2n.
Group II, *Subrhamnifolii*	
R. nitidus subsp. opacus Focke [2]	28
Group III, *Rhamnifolii*	
R. imbricatus Hort.	28
R. incurvatus Bab.	28
R. Lindleianus Lees.	28
Group IV, *Villicaules*	
R. villicaulis W. & N. (= Koel ? [3])	28
" R. (? Selmeri) "	28 Crane and Darlington
Group V, *Discolores*	
R. rusticanus Merc.	14
R. rusticanus Merc. var. inermis	14 Crane and Darlington
Group VII, *Vestiti*	
R. Sprengelii Weihe	28
Group X, *Sub-Koehleriani*	
R. Bloxamii Lees.	28
Group XI, *Sub-Bellardiani*	
R. thyrsiger Bab.	28 Crane and Darlington
Group XIV, *Caesii*	
R. corylifolius Sm.	35
R. caesius L.	28

In conclusion I must express very grateful thanks to Professor Lapworth for his kindness in providing and identifying the material. I am also indebted to Dr. I. Manton for advice and for help in the preparation of the manuscript.

[2] The Rubus described as "R. nitidus subsp. opacus *Focke*" is common in shady places in the region between Macclesfield and Knutsford. It does not correspond quite satisfactorily with Moyle Rogers' description, and has some affinity with R. plicatus.—A. L.

[3] The specific determination was in this instance made from Babington's *British Rubi*, and Professor Lapworth kindly supplies the following note: "The 'R. villicaulis W. & N. (= *Koel?*)' is the typical British form of R. villicaulis *Koel*, differing from the latter in having the inflorescence nearly or quite eglandular. It is most readily distinguished from R. Selmeri *Lindeb.*, which can frequently be found growing within a few yards of it in the Macclesfield-Knutsford district. Sudre places villicaulis and Selmeri, apparently with good reason, in distinct divisions of the Rubi."—A. LAPWORTH.

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IX.—The Relative Value of Fossil Plants in the Stratigraphy of the Coal Measures.

By R. Crookall, D.Sc.

I.—Introduction.

The various genera and species of Coal Measure plants have very different values in their application to stratigraphical purposes. In assessing their relative value in this respect, it is necessary to distinguish between forms which can be used in *general* correlation, i.e. in the recognition of the four palæobotanical divisions of the Coal Measures,[1] and those which may be of only *local* use.

It must, however, be pointed out that non-zonal fossils may (or may not) possess considerable biological or other interest.[2]

In the following pages a number of forms will be indicated which have little or no general correlative value, but these may give assistance in local correlation. For example, the roof-shales of a particular coal may be characterised over a considerable area by the presence of Lycopod remains, and even imperfectly preserved stems of these plants can often

[1] The Lanarkian, Yorkian, Staffordian and Radstockian Series (the Lower, Middle, Transition and Upper Coal Measures respectively).

[2] In addition to their stratigraphical value, fossil plants provide information as to (1) *Climatology* (see, for example, Professor A. C. Seward's "Fossil Plants as Tests of Climate," London, 1892). (2) *Evolution* (Dr. D. H. Scott's "Studies in Fossil Botany," London, 3rd ed., Vols. i, ii, 1920). (3) *Plant geography* (Professor Seward's "Plant Life through the Ages," Cambridge, 1931). (4) *Ecology and physiography* (D. Davies, *in Phil. Trans. Roy. Soc. Lond.*, B, Vol. 217, 1929, p. 34). (5) *Atmospheric conditions.* (6) *Conditions under which plant-debris accumulated to form coal* (D. H. Scott, *in Trans. Inst. Min. Eng.*, Vol. liv, 1917-18, p. 33). (7) *Conditions under which certain strata were deposited*, etc.

be recognised as such. Again, various species of *Calamites* may be the dominant elements in the flora of a seam, although specifically identifiable examples may be rare, and some "species" may be without general correlative value. In such cases local conditions favoured the development of a particular type of vegetation over a given area.

A few examples of the use of fossil plants in local correlation are here cited.

Mr. T. H. Rowlands [1] found that the plants in the shales above the coal-seams in the western portion of South Wales were distinctive, enabling the seams to be traced along the outcrops for a considerable distance, while the characteristic floras of a number of coals in South Wales have been published by the late David Davies.[2, 3] At the Cefn Coed Sinkings, near Swansea, Mr. W. D. Ware [4] obtained valuable correlative evidence from the fossil plants encountered. Mr. S. Bates [5] collected both plant and animal fossils from the seams in the Wylam district, and found that with one or two exceptions, "the fauna and flora had horizons practically of their own. Commencing from the Brockwell and lowest seam, there was a bed of shale . . . containing a great number of *Anthracosia*. . . . At the Six-quarter Seam . . . the fauna was absent, but *Sphenopteris* and *Pecopteris* were very common, with a number of *Calamites*. The Five-quarter Seam occurred with the above mentioned flora, with the addition of *Asterophyllites*, which had not yet been found near the Six-quarter Seam." In Yorkshire, Professor P. F. Kendall [6] found the roof of the Barnsley Bed at South Kirby was particularly rich in plants,

[1] Rowlands, T. H., "The Correlation of the Coal Measures in the Western Portion of the South Wales Coalfield," *S. Wales Inst. Eng.*, Vol. 41, 1925, p. 257.

[2] Davies, D., "The Ecology of the Westphalian," etc., *Quart. Journ. Geol. Soc.*, Vol. 77, 1921, pp. 30-74.

[3] "Correlation and Palæontology of the Coal Measures in East Glamorganshire," *Phil. Trans. Roy. Soc. Lond.*, B, Vol. 217, 1929, pp. 34-40.

[4] Ware, W. D., "An Account of the Geology of the Cefn Coed Sinkings," *S. Wales Inst. Eng.*, Vol. 46, 1930, pp. 453-494.

[5] Bates, S., *in Trans. Inst. Mining Eng.*, Vol. 30, 1905-06, p. 459.

[6] Kendall, P. F., *in litt.*

of which *Neuropteris heterophylla* was the most characteristic species. At Ackton Hall the Middleton Main, on the south side of the pit, is characterised by *Sigillaria* in the roof: on the other hand, the Hard Bed Band Coal at Meanwood, Leeds, is associated with *Lepidodendron*, *Sigillaria* being absent. Shales above the Halifax Hard Bed contain numerous *Cordaites*, while the roof of the Haigh Moor Seam at Robin Hood Quarries, Wakefield, is very prolific in *Lepidodendron*.

It will assist further discussion if the various groups of Coal Measure plants, and the genera to which they have given rise, are indicated.

II.—Plant Groups in the Coal Measures.

Group.	Rhizomes and Roots.	Stems.	Leaves.	Fructifications.
Lycopodiales ("club mosses")	*Stigmaria*; *Stigmariopsis*	*Lepidodendron*; *Lepidophloios*; *Sigillaria*; *Bothrodendron*; *Asolanus*	*Sigillario-phyllum*; *Lepidophyllum*	*Lepidostrobus*; *Sigillariostrobus*
Spheno-phyllales	*Pinnularia*		*Sphenophyllum*	
Equisetales ("horsetails")	*Pinnularia*	External casts: *Calamophloios*; *Dictyocalamites*. Pith casts: *Calamites*	*Annularia*; Leafy twigs: *Asterophyllites* (= *Calamo-cladus*)	*Calamostachys*; *Palæostachya*; *Macrostachya*; *Volkmannia*
Filicales (ferns)	*Pinnularia*	(Tree-ferns) *Megaphyton*; *Caulopteris* *Ptychopteris*	*Pecopteris* (some species) *Sphenopteris* (some species)	Spore-cases occur on leaves
Pteridosperms (seed-ferns)	*Pinnularia*		*Alethopteris*; *Linopteris*; *Neuropteris*; *Odontopteris*; *Mariopteris*; some species of *Pecopteris* and *Sphenopteris*	(*a*) micro-sporangia occur on leaves. (*b*) seeds. *Trigonocarpus*; *Lagenostoma*; *Carpolithus*; *Samaropsis*, etc.
Cordaitales	*Pinnularia*	Pith-casts: *Artisia* (= *Sternbergia*)	*Cordaites*	(*a*) catkins. *Cordaianthus*. (*b*) seeds. Some species of *Samaropsis*, *Carpolithus*, etc.

III. PLANT PARTS.

(*a*) *Leaves.*

Dealing with the various plant organs, the great majority of diagnostic forms are leaves, and especially those of the Ferns and Pteridosperms, representing by far the commonest Coal Measure plants. These are mainly distinguished by their form and venation, and the writer has published a Table [1] by means of which the chief genera can readily be recognised. A brief note may, however, be desirable with regard to the venation. In such genera as *Mariopteris*, *Alethopteris*, *Linopteris* and *Lonchopteris* [2] the veins are almost always clearly marked. Pecopterids, similarly, have well-marked veins (except in one or two species where they may be masked by the presence of hairs: thus, in *Asterotheca abbreviata* (Brongniart) hairs may be preserved on the upper surface of both the fertile and the sterile leaflets, while in *A. oreopteridia* (Schlotheim) they may occur on the fertile pinnules only. These are Radstockian species). Among the Sphenopterids, however, though veins are clearly shown in many species (e.g. *Sphenopteris dixoni* Kidston,[Y] *S. footneri* Marrat,[Y] *S. kayi* Arber [Y] and *S. woodwardi* Kidston [R]), in others, for various reasons, and chiefly when immersed in the tissue, they may be obscure or not shown. In some of these a midrib can be made out, but in others even this cannot usually be observed. In such instances the veins can often be revealed by special treatment, the epidermis being removed. Sphenopterids with obscure venation can, nevertheless, be recognised by the form and texture of the fronds and the rachis and its markings. They include *Sphenopteris bella* (Stur),[Y] *S. coriacea* Marrat,[Y] *S. dilatata* Lindley and Hutton,[Y] *S. fentoniana* Kidston, *S. hulseni* [L] Gothan, *S. marrati* Kidston,[Y]

[1] Crookall, R., " Coal Measure Plants," London, 1929, p. 49.

[2] It is remarkable that those leaves with a net-like venation which are placed in the genus *Lonchopteris* are markedly commoner on the Continent than in Britain.

R = Radstockian Series; S = Staffordian Series; Y = Yorkian Series; L = Lanarkian Series. *S. spiniformis* is more common in the Yorkian than in the Lanarkian.

S. nummularia Gutbier,[Y] *S. sauveuri* Crépin,[Y] *S. spiniformis* Kidston,[Y & L] *S. spinosa* Goeppert,[S & Y] and *S. trifoliolata* (Artis)[Y & L]. Leaves of *Neuropteris* are usually preserved with well-marked veinlets, but if these are not shown specific identification is not possible.

Pecopterids, as a body, are characteristic of the Radstockian Series: *Lonchopteris*, though of somewhat rarer occurrence, is very typical of the Yorkian (no records being known from outside that division), while an abundance of species of *Linopteris* marks the Staffordian. The Lanarkian has several typical forms of *Sphenopteris*.

Cyclopteroid leaves (*Cyclopteris*) are often found isolated from the fronds which bore them and can usually be neglected. The crosier-like coiled apices of the fronds of Ferns and Pteridosperms (designated *Spiropteris*) are of much rarer occurrence and are clearly valueless unless, as is seldom the case, the species to which they belong can be recognised. The fossil can occur in any plant-bed, whether of Lower or Upper Carboniferous age, containing fern or fern-like remains.

The leaves of *Sphenophyllum* provide several common and diagnostic species, as do also those of the Equisetales (*Annularia*), but some of the leafy twigs (*Asterophyllites* = *Calamocladus*) of this group are less well defined and consequently of limited value.[1]

The grass-like leaves known as *Sigillariophyllum* have no stratigraphical value, as they were borne on a number of species of *Lepidodendron* and *Sigillaria*. As a rule, leafy twigs of the Lycopods are difficult to identify, though in a few cases (e.g. *Lepidodendron acutum* (Presl), *lanceolatum* Lesquereux, *L. ophiurus* Brongniart, *L. wortheni* Lesquereux, *L. lycopodioides* Sternberg and *Bothrodendron minutifolium* (Boulay) the size and form of the leaves and the angle at which they are given off are somewhat distinctive.[2]

Y See note on opposite page.

[1] *Asterophyllites longifolius*, though not a "guide" species, is an "auxiliary species" in certain Continental coalfields, and may prove of value in Britain.

[2] See Crookall, R., "*Coal Measure Plants*," London, 1929, Pls. IV and V.

Leaves of the Cordaitales (*Cordaites*) are common fossils on certain horizons, and include zonal fossils. *C. anguloso-striatus* Grand 'Eury, very frequent in the Radstockian Series, is, however, a poorly defined species.

(*b*) *Stems.*

Second to leaves as stratigraphical indices come various stems, and particularly those of the Lycopodiales—*Lepidodendron*, *Lepidophloios*, *Sigillaria*, *Bothrodendron*, etc. For the present purpose, however, from stem-remains can be excluded those which bear merely longitudinal markings, spines or hairs (belonging chiefly to the Ferns and Pteridosperms) and those stems of the Lycopodiales which, by decay or injury, have lost part of their outer tissues and thus lack definite leaf-cushions or leaf-scars. Some species of Lycopod stems appear to have been particularly liable to "decortication": others resisted decay and are almost always found perfectly preserved. To accommodate imperfectly preserved Lycopod stems various "genera" have been instituted—*Bergeria*, *Aspidiaria*, *Knorria*, *Halonia* and *Syringodendron*. Unless a portion of the fossil bears recognisable leaf-cushions,[1] these forms are useless for general correlation. In the first-named, the epidermal and sub-epidermal tissues were lost, and in *Aspidiaria* the markings observed are due to still deeper cortical tissues. To produce Knorria decay had proceeded to a still deeper level and the irregularities shown are due to tissues in the middle cortex. *Ulodendron* stems (having large cup-shaped depressions, up to 12 cm. or so in diameter) which do not also bear well-marked leaf-cushions or leaf-scars are valueless, and occur in both the Lower and Upper Carboniferous. It may be observed that it is not unusual to find the cast of an isolated scar (which may be mistaken for an oval shell). Reference must also be made to stems of Lycopods which, though well preserved and bearing leaf-cushions or leaf-scars, have a comparatively great vertical distribution. As a rule, however, these are markedly com-

[1] Specimens of *Halonia*, for example, may bear leaf-cushions of the *Lepidophloios* type.

moner in certain divisions. Thus, *Lepidodendron aculeatum* Sternberg, though ranging throughout the Coal Measures, is much more frequent in the two lower Series. Other forms provide common and characteristic species. For example, *Sigillaria cumulata* Weiss (formerly confused with the Yorkian *S. tessellata* Brongniart) is typical of the Radstockian.

Although the genera *Lepidodendron*, *Lepidophloios*, *Sigillaria* and *Bothrodendron* thus provide a number of well-marked and commonly occurring zonal species, the genus *Asolanus* is known from all divisions with the exception of the Lanarkian. A single species—*A. camptotænia* Wood—is at present recognised in Britain. In this form the leaf-scars are spirally arranged and distant from each other.

The stems of tree-ferns (*Caulopteris*, *Megaphyton* and *Ptychopteris*) are usually too rare to be of much stratigraphical value, though certain forms included in the first two genera are found in the Radstockian and others in the Yorkian Series.[1] *Ptychopteris* represents stems of tree-ferns which were decorticated before preservation. External casts of the stems of the *Cordaitales* (*Cordaicladus*) are rarely recognised and cannot, as a rule, be correlated with the leaf-species. The moulds and casts of the outer surface of stems of the Equisetales are comparatively rare, and it may be said that the remains of Equisetacean stems are not, as a rule, of great general correlative value within the Coal Measures.[2]

[1] One or two examples only of each species has been recorded. Radstockian forms include *Caulopteris anglica* Kidston, *C. arberi* Kidston, *C. cyclostigma* Lesquereux, *C. germari* Kidston, *C. peltigera* (Brongniart), *C. primæva* Lindley and Hutton, and *Megaphyton elongatum* Kidston. Yorkian forms of *Megaphyton* are *M. anomalum* Grand 'Eury, *M. approximatum* Lindley and Hutton, *M. goldenbergi* Weiss and *M. souchi* Zeiller.

[2] The genus *Calamites* includes two groups: (*a*) one in which the ribs alternate at the nodes, non-alternation, though occasionally present in one or two ribs, being rare, and (*b*) a smaller group in which alternation and non-alternation are constantly found on one and the same specimen. In this group the ribs always show both arrangements at each node. In *Asterocalamites*, on the other hand, the ribs are not alternate, but are continuous through the nodes. This is a Lower Carboniferous genus, and it is interesting to note

In discussing this point, it is first necessary to distinguish between the various forms represented and to indicate the origin of the markings they bear. This is done in the Table given below:—

REMAINS OF THE STEMS OF THE EQUISETALES.[1]

Origin of Markings shown.	Features Present.				
	Nodes.	Infra-Nodal Canals.	Branch-Scars.	Leaf-Scars.	Root-Scars.
The inside of the woody cylinder—(pith-casts)—CALAMITES	present	present	sometimes present	absent	absent
Some region within the secondary wood (sub-medullary casts) CALAMITES	present	absent	sometimes present	absent	absent
Outer surface of the secondary wood CALAMITES	absent	absent	sometimes present	absent	absent
The tissues in the cortex ("sub-cortical casts") CALAMITES	present	absent	sometimes present	absent	absent
The external features of the stem (external casts) CALAMOPHLOIOS and DICTYOCALAMITES	present	absent	sometimes present	may be present at nodes	may be present at or near nodes.

Of the above, sub-medullary casts (from which infra-nodal canals are absent) and those external casts which have not been correlated with their pith-casts are non-zonal.

that group (*b*) is not only intermediate in form between *Asterocalamites* and group (*a*), but it also occupies an intermediate geological position.

[1] See Arber, E. A. N. and Lawfield, F. W., "On the External Morphology of the Stems of *Calamites*, with a Revision of the British Species of *Calamophloios* and *Dictyocalamites* of Upper Carboniferous Age," *Journ. Linn. Soc.*, Vol. xliv, 1920, p. 507.

The following Table is based on the correlations arrived at by Arber and Lawfield:—

External Cast (*Calamophloios and Dictyocalamites*).	Corresponding Pith-Cast.	Internodes.	Bark.	Leaf-Scars.	Branch-Scars.
C. britannicus (Kidston)	unknown	generally broader than long	smooth	small	elliptical; many on each node; alternating
C. congenius (Renault)	*C. cruciatus* (Sternberg) (pars)	very short—much broader than long	smooth	unknown	rounded; many on each node; alternating
C. rugosus (Arber)	*C. carinatus* (Sternberg) and *C. paleaceus* (Stur)	generally longer than broad	pitted and longitudinally striated	unknown	2 on each node; alternating
C. goepperti (Ettingshausen)	? *C. approximata* (Brongt.) = *C. schutzei* ? = *C. varians* (Sternberg) = *C. undulatus*	vary much in length	smooth or faintly striated, with distant vertical cracks	oval; 2-2½ mm. broad	10-12 in a whorl
C. majus (Feistmantel)	? *C. varians* (Sternberg) (pars)	often shorter than broad	longitudinally striated	oval; closely placed	generally crowded
C. discifer (Weiss)	unknown	vary	fine, longitudinal striæ	large; circular	irregular
C. sachsei (Stur)	*C. sachsei* (Stur)	generally longer than broad	smooth or very fine longitudinal striæ	small	small or of medium size
C. undulatus (Arber)	*C. undulatus* (Sternberg)	?	transverse wrinkles	elliptical	small; elliptical or circular
C. suckowi (Brongniart)	*C. suckowi* (Sternberg)	usually broader than long	smooth	small; distinct; obscure	rare or absent
D. burri (Arber)	unknown	generally longer than broad	reticulate	?	?

It will be seen that, apart from those rare external casts and moulds which have been correlated with their pith-casts, only pith-casts bearing nodes and infra-nodal canals should be collected for purely stratigraphical purposes. Even some of these, by reason of their great vertical range, are of little or no use. This applies especially to *Calamites suckowi* Brongniart, occurring in all divisions of the Coal Measures. It is distinguished by the bluntly rounded angle shown at the tops of the ribs and by the upper tubercles being oval or circular. *Calamites carinatus* (Sternberg) (= *C. ramosus* Artis) is similarly distributed. In this form of pith-cast the branch-scars have a characteristically large central opening, and the ribs bend in towards it. In addition to these, a number of species of *Calamites* are common to both the Yorkian and the Lanarkian—*C. cisti* Brongniart, *C. undulatus* Sternberg, *C. sachsei* Stur and *C. goepperti* Ettingshausen. This is also true of the leaves *Annularia radiata* Brongniart and *A. galioides* (Lindley and Hutton), as well as of the leafy twigs known as *Asterophyllites equisetiformis* (Schlotheim) and *A. charæformis* (Sternberg). *A. equisetiformis*, occurring throughout the Coal Measures, is without general correlative value.[1] *Phragmæ of Calamites*—circular fossils often bearing radiating leaves—due to the liability of these stems to break at the nodes, and representing transverse impressions of nodes, are generally of no value. The pith-casts of roots are somewhat rare and quite valueless. While those of *Stigmaria* are usually smooth, pith-casts of *Stigmariopsis* bear ribs, thus simulating *Calamites*, but nodes are absent.

The Cordaitean pith-casts known as *Artisia* (= *Sternbergia*) are quite valueless from the stratigraphical standpoint. They occur in both Lower and Upper Carboniferous rocks, and may be found in all divisions.

(*c*) *Fructifications.*

For unassignable spore-cases of the Lycopods, Lesquereux instituted the " genus " *Lepidocystis*. Some of these sporangia

[1] See, however, p. 92, where *Asterophyllites* has been of use in local correlation. *A. longifolius*, *A. grandis* and *A. charæformis* may have minor correlative value.

had previously been included with ill-defined seeds under Linnaeus' genus *Carpolithus.* Such fossils may be fairly frequent in beds containing numerous Lycopod remains. The leaves of ferns which bear sporangia (and of Pteridosperms bearing microsporangia) have already been noted as including our commonest and most frequent diagnostic forms. Such fertile leaves are removed from the form-genera and placed in more satisfactory groups based upon the type of fructification borne. Thus, fertile forms of Pecopteroid leaves are included in *Acitheca*, *Asterotheca*, *Ptychocarpus*, etc., while fertile Sphenopteroid leaves are placed in such genera as *Telangium*, *Boweria*, *Renaultia*, *Oligocarpia*, *Urnatopteris*, *Senftenbergia*, *Corynepteris*, *Radstockia* and (some species) *Crossotheca.*

Seeds,[1] unless correlated with their foliage, are of little stratigraphical value as a rule, chiefly because of their comparative rarity and local distribution. Though some show well-marked features, many are ill-defined and have to be grouped in a comprehensive "genus" *Carpolithus. Carpolithus* includes numerous forms, some belonging to the Pteridosperms and others to the Cordaitales. On the other hand, certain seeds may be diagnostic as between the Radstockian Series and the divisions below, or *vice versa.* Thus, *Trigonocarpus nœggerathi* (Sternberg), probably representing the seed of the Pteridosperm *Alethopteris serli-grandini* (Brongniart), is a fairly common Radstockian form, while *T. parkinsoni* Brongniart, belonging to *A. lonchitica* (Schlotheim) is abundant in the Yorkian and less so in the Lanarkian. Again, of the genus *Samaropsis* (Elm-like seeds) some of which belong to the Pteridosperms and others to the Cordaitales, *S. acuta* (Lindley and Hutton) is not found above the Yorkian Series and is fairly frequent at some localities. It is probably to be correlated with the foliage known as *Eremopteris artemisæfolia* (Sternberg).

Fertile cones of certain Pteridophytes (Lycopodiales,

[1] As was first realised by Mr. W. Hemingway, some apparent "seeds" of the Coal Measures are shown by Professor T. G. Halle to be spore-capsules.

Equisetales and Sphenophyllales),[1] though of great botanical interest, do not often yield stratigraphical results as they are of fairly rare occurrence and, in some instances, lack definiteness. Those of the Lycopodiales are placed in the genera *Lepidostrobus* and *Sigillariostrobus*. Ill-defined forms are included under Lindley and Hutton's *L. variabilis*, a fructification therefore recorded from both the Lower and the Upper Carboniferous. *L. squarrosus* Kidston,[2] though rare, is more clearly defined and occurs in the Yorkian. Detached bracts from the cones of the Lycopodiales vary greatly in size and form, often being lance-shaped or shaped like arrow-heads, and have little zonal effect. They have a single central vein. If the sporangia have been shed, such bracts may be indistinguishable from some sterile leaves (*Lepidophyllum*).

Strobili of the Equisetales, comparatively rare fossils, are placed in the genera *Calamostachys*, *Palæostachya*, *Macrostachya* and *Volkmannia*, the last-named including poorly defined forms. *Macrostachya infundibuliformis* (Brongniart), *Calamostachys tuberculata* (Sternberg) [3] and *Stachannularia calathifera* Weiss [4] are Radstockian forms, while *C. longifolia* Weiss, *C. ludwigi* (Carruthers), *C. paniculata* Weiss, *C. ramosa* Weiss, *C. rœhli* Stur, *C. typica* Schimper, *Palæostachya ettingshauseni* Kidston, *P. gracillima* Weiss and *P. pedunculata* Williamson occur only below the Radstockian.

The microsporangiate and seed-bearing catkins of the Cordaitales (*Cordaianthus* = *Antholithus*) are usually common only where the leaves of *Cordaites* also occur in great abundance. *C. pitcairniæ* (Lindley and Hutton) is common, and *C. volkmanni* (Ettingshausen) rather less frequent in the Yorkian. The seeds of this group of plants are often found detached. They are placed in the genera *Samaropsis* and *Cordaicarpus*, according as they are winged or not. In some cases the distinctions between these genera (and between

[1] The term "*Sphenophyllostachys*" for cones of *Sphenophyllum* is unnecessary.

[2] *L. squarrosus* (= *L. variabilis* Schimper and Zeiller) has more lax and spreading bracts than *L. variabilis* L. and H.

[3] This is the cone of *Annularia stellata*.

[4] The cone of *Annularia sphenophylloides*.

some of the species they contain) are somewhat arbitrary. *Cordaicarpus cordai* (Geinitz) and *C. crassus* (Lesquereux) are, however, mainly found in the Yorkian Series, and the same is true of *Samaropsis marginata* (Artis), *S. acuta* (L. and H.), *S. orbicularis* Ett. and *S. meachemi* (Kidston). *S. arberi* Kidston, on the other hand, is a Staffordian form.

Detached microsporangia of the Pteridosperms are too rare and locally distributed to be of much use in correlation. The rare *Neuropteris carpentieri* represents modified fertile pinnules, found in the Yorkian.

Whittleseya, a rare Yorkian form, is a spore-case. The Yorkian "seed" *Holcosperma* (*Rhabdocarpus*) *elongatum* has been proved by Professor Halle to be a spore-case.

(*d*) *Roots and Rhizomes.*

Roots and rootlets generally, on account of the uniformity of the conditions under which they lived, show few or no distinctive features and most are therefore negligible—those referred to the genera *Stigmaria* and *Pinnularia* (= *Radicites* = *Myriophyllites*). It is usually impossible to determine to which genus, as based on stems or leaves, these organs belonged. *Stigmaria ficoides* (Sternberg) probably the commonest fossil of the Coal Measures, occurs in both the Lower and the Upper Carboniferous and is found in all divisions of the latter. *Omphalophloios anglicus* (Sternberg), the cortex of which bears rhomboidal markings, is, however, confined to the Radstockian. *Stigmariopsis* occurs very rarely in our Coal Measures. It probably represents the rhizophore of the non-ribbed *Sigillarias* which characterise the *Stephanian* and Permian of the Continent.[1]

The various forms which are found to be of limited (in some cases of no) value in recognising the four divisions of the Coal Measures are summarised in the Table given herewith.

[1] *Stigmariopsis* is shorter, thicker and more rapidly tapering than *Stigmaria* and the surface bears fine irregular meshes.

FORMS OF LIMITED VALUE IN GENERAL CORRELATION.

Group.	Forms.
LYCOPODIALES	Stems lacking leaf-cushions or leaf-scars—*Bergeria, Aspidiaria, Knorria, Halonia, Syringodendron.* Some leafy twigs of *Lepidodendron* and *Sigillaria.* Some fertile cones included in *Lepidostrobus* and *Sigillariostrobus.* Bracts detached from cones—*Lepidophyllum.* Leaves (lanceolate or grass-like)—*Lepidophyllum* and *Sigillariophyllum.* Unassigned spore-cases—*Lepidocystis.* Most roots and rhizomes—*Stigmaria.*
SPHENOPHYLLALES	Some cones—*Sphenophyllostachys.* Roots—*Pinnularia* = *Myriophyllites* = *Radicites.*
EQUISETALES	Outer surface of stems (uncorrelated with pith-casts)—*Calamophloios.* All pith-casts—*Calamites*—lacking nodes. Certain pith-casts with nodes—*Calamites suckowi, C. cisti, C. carinatus.* Some leafy twigs — especially *Asterophyllites equisetiformis.* Nodes seen in cross-section (phragmæ). Some cones, especially *Volkmannia.* Roots—*Pinnularia.*
PTERIDOSPERMS and FILICALES	Some leaves not showing venation (e.g. those of *Neuropteris*). Coiled tips of fronds—*Spiropteris.* Cyclopteroid leaves—*Cyclopteris.* Some stems, especially *Ptychopteris.* Stems bearing only longitudinal marks, spines or hairs. Detached microsporangia of Pteridosperms—e.g. *Whittleseya.* Some seeds, especially *Carpolithus.* Roots—*Pinnularia.*
CORDAITALES	Pith-casts—*Artisia* = *Sternbergia.* Some catkins—*Cordaianthus* = *Antholithus.* Some seeds, especially *Carpolithus.* Stems—*Cordaicladus.* Roots.

IV. DIAGNOSTIC SPECIES.

Moulds and casts of the stems of the Lycopodiales are mainly found in the Yorkian Series which contains numerous species of *Sigillaria* and *Lepidodendron.* Certain species of these genera are, however, common to both the Yorkian

and the Lanarkian (e.g. *Lepidodendron aculeatum* Sternberg, *L. obovatum* Sternberg, *Sigillaria scutellata* Brongniart and *S. tessellata* Brongniart) and therefore are not diagnostic as between these divisions. *Asolanus* occurs throughout the Coal Measures, with the exception of the Lanarkian Series. Two species of the genus *Lepidophloios* are found in the lower two divisions, *L. laricinus* Sternberg being more common in the Yorkian and *L. acerosus* Lindley and Hutton in the Lanarkian. *Sigillaria elegans* Brongniart, though found in the Yorkian, is more frequent in the Lanarkian. *Bothrodendron punctatum* L. and H., is common in and restricted to the Yorkian: *B. minutifolium* (Boulay) occurs in both of the lower divisions, though more commonly in the Yorkian.

Turning to the Sphenophyllales, *Sphenophyllum cuneifolium* (Sternberg) and *S. myriophyllum* Çrépin are known from both the Yorkian and Lanarkian, though they are more common in the former. Other species of the genus—*S. majus* Bronn and *S. saxifragæfolium* (Sternberg) are typical of the Yorkian, though *S. majus* is almost as frequent in the Staffordian. While *S. emarginatum* Brongniart is a common Radstockian plant, it is not infrequent in the Staffordian. A characteristic form of the Lanarkian is *S. amplum* Kidston pro sp., formerly regarded as a variety of *S. cuneifolium.*

The leaves of the Equisetales are of more value than the pith-casts (which have been dealt with above). In the Radstockian we find *Annularia sphenophylloides* (Zenker) and *A. stellata* Schlotheim. *Annularia microphylla* Sauveur is a Yorkian species and, though *A. galioides* (Lindley and Hutton) is also found in the Lanarkian, it is more frequent in the Yorkian. The leafy twigs designated *Asterophyllites* (= *Calamocladus*) have already been noted as of comparatively small value, as they are not well defined. *A. equisetiformis* (Schlotheim) occurs on a number of horizons, and though *A. charæformis* (Sternberg) is found in both the lower divisions it is unknown from the Radstockian. The same is true of *A. grandis* (Sternberg) and *A. longifolius* (Sternberg). *A. charæformis* probably represents the leaves of *Calamites undulatus* Sternberg.

It has been observed above that the leaves of the Ferns

and Pteridosperms provide by far the most reliable zonal plants. Thus, in the Radstockian there are many species of *Pecopteris* some of which, on the basis of the spore-cases borne on the leaves, are now referred to more satisfactory genera—*Acitheca*, *Asterotheca*, *Ptychocarpus*, etc. While the numerous Pecopterids of the *cyathea* group, as a group, characterise the Radstockian (and occur, more rarely, in the Staffordian), some few Pecopteroid plants occur in the Yorkian and Lanarkian, but these are of a different type. The pinnules of the Radstockian Pecopterids are tongue-shaped and the venation is distinctive: those from lower divisions are not tongue-shaped and generally possess a more lax venation which is often Sphenopteroid. The Pecopterid *Dactylotheca plumosa* (Artis) is very common in the Yorkian. Although some Sphenopterids occur in the Radstockian (*Sphenopteris macilenta*, *S. neuropteroides*), many more species are found in the Yorkian (when fertile being placed in the genera *Oligocarpia*, *Renaultia*, *Urnatopteris*, etc.). Lanarkian species include *Sphenopteris hœninghausi*, *S. bæumleri* and *Mariopteris acuta*. *Mariopteris*, a difficult genus to separate into readily recognised species, provides *M. nervosa* as a common Yorkian plant. The genus *Linopteris* characterises the Staffordian, being there represented by *L. obliqua* (Bunbury) and *L. münsteri* (Eichwald). *Lonchopteris*, on the other hand, is essentially a Yorkian genus. Under *Alethopteris* are included species which are typical of the various divisions of the Coal Measures. The characteristic Radstockian form is *Alethopteris serli-grandini* Brongniart, a very common plant in the Upper Coal Measures, but occurring, though rarely, in the Yorkian and occasionally (apparently) even lower. There is a single record of the species from the Bideford Beds of Devon, which are regarded as of Lanarkian age.[1, 2]

[1] Arber, E. A. N., "The Fossil Flora of the Culm Measures of North-West Devon, and the Palæobotanical Evidence with regard to the Age of the Beds," *Phil. Trans. Roy. Soc. Lond.*, B, Vol. 197, 1904, p. 291.

[2] Crookall, R., "The Plant Horizons Represented in the Barren Coal Measures of Devon, Cornwall and Somerset," *Proc. Cottes. N.F.C.*, Vol. xxiv, 1932, p. 27.

It may also be pointed out that Kukuk [1] places the incoming of *A. serli* in Westphalia very little above the equivalent of our Halifax Hard Bed = the Bullion Mine = the Upper Foot Mine, in the Lower Coal Measures. *A. davreuxi* Brongniart has probably been misidentified in Britain and may yet prove a useful Upper Yorkian species. *A. lonchitica* (Schlotheim) and *A. decurrens* (Artis) belong to the Yorkian and Lanarkian divisions, being especially frequent in the former.

Of the Neuropterids, *Neuropteris ovata* Hoffmann,[2] *N. flexuosa* Sternberg, *N. macrophylla* Brongniart, *N. rarinervis* Bunbury and *N. scheuchzeri* Hoffmann are found plentifully in the Radstockian and Staffordian Series, while *N. heterophylla* Brongniart, *N. gigantea* Brongniart, *N. obliqua* Brongniart and *N. tenuifolia* Schlotheim are typical Yorkian forms. The Lanarkian is characterised by *N. schlehani* Stur, a form of which is known as *N. rectinervis* Kidston.[3] (It is

[1] Kukuk, P., in *Congrès de Stratigraphie Carbonifère, Heerlen,* 1927, published Liége, 1928, p. 414.

[2] Bertrand and Corsin, have proposed the name *Mixoneura anglica* for the British plants referred to this species.

[3] *Neuropteris rectinervis* was described by Kidston in 1888 ("On *Neuropteris plicata* Sternberg and *Neuropteris rectinervis* Kidston n.sp.," *Trans. Roy. Soc. Edinb.*, Vol. xxxv, Pt. I (Nos. 5, 6), pp. 313-335, pl.) and in 1929 the writer ("*Coal Measure Plants,*" London, 1929, p. 60) pointed out that the species "appears to merge into *N. schlehani.*" Although Professor Gothan and Dr. F. Franke ("Der Westfälisch-Rheinische Steinkohlenwald und seine Kohlen," Dortmund, 1929, pp. 44-46) separate the two, from a careful comparison of a number of specimens, the writer is satisfied that Kidston's species is identical with Stur's *N. schlehani.* Specimens occur bearing both "forms" of foliage. For example, in 1904, Arber ("The Fossil Flora of the Culm Measures of North-West Devon," *Phil. Trans. Roy. Soc. Lond.*, B, Vol. 197, Pl. 20, Figs. 11, 15, p. 305) figured—as *Alethopteris lonchitica* (Schloth.)—a specimen from near Bideford, observing that the pinnules were not decurrent and that this form "is apparently very common in the Culm Measures." The fossil is preserved in the Museum of Practical Geology and is numbered 8423. Arber had subsequently revised his identification, calling it *N. rectinervis.* While, however, the top of the frond in question is *N. rectinervis* Kidston, the lower portion is a typical example of Stur's *N. schlehani.* Kidston's species must, therefore, be regarded as a synonym of Stur's. *Neuropteris schlehani*

sometimes difficult, however, to distinguish between this species and forms of *Alethopteris lonchitica*, especially in fragmentary remains.) *Odontopteris* characterises the Radstockian. *Mariopteris acuta* is mainly found in the Lanarkian, while *M. nervosa*, though present in the Lanarkian, is one of the commonest plants of the Yorkian. *M. plumosa* appears to be confined to the Radstockian, where, however, it is rare. Other, more or less rare, Yorkian forms are *M. beneckei*, *M. dernoncourti*, *M. jacquoti*, *M. lobatifolia*, *M. loshi*, *M. obovata*, and *M. sauveuri*. *M. latifolia* is a Staffordian plant.

Turning to the Cordaitales, in the Radstockian we find the somewhat rare, though readily recognised, *Poacordaites microstachys* (Goldenberg) and the very common *Cordaites angulosostriatus* Grand 'Eury, the latter being a broad-leaved but ill-defined form. *Cordaites borassifolius* (Sternberg) and *Dorycordaites palmæformis* (Goeppert) are Yorkian leaves, but *C. principalis* (Germar) is found in both of the lower divisions.

Hitherto, the plant species which characterise the Staffordian Series (Transition Coal Measures) have been merely designated as a mixture of Radstockian and Yorkian forms—a not very satisfactory definition. Although the floras are

Stur thus includes small-leaved forms where the pinnules are 8-15 mm. long by 4-8 mm. broad, and large-leaved forms in which they measure 20-30 mm. long by 5-8 mm. broad, the latter being the *N. rectinervis* of Kidston. The base of the pinnules is rounded, the margins slightly arched and the apex rounded or bluntly pointed. The central vein is strongly marked and continues almost to the apex. The lateral veins are also clearly shown and divided once or twice. There are slight differences between the small and large-leaved forms. In the smaller pinnules the lateral veins take a more slanting course than in the large and do not meet the margin quite at a right angle: they generally fork twice and may be very slightly flexuous. In the larger pinnules, whose margins are less arched, very soon after leaving the central vein, the veinlets take a straight course for the margin, meeting it practically at right angles. Here they usually divide once, and only occasionally twice. In each case the apical pinnule is long and linear, being often markedly longer than the adjacent lateral pinnules. In the small-leaved forms this leaflet is 7-15 mm. long. In shape, the large pinnules resemble *Alethopteris serli* Brongniart, but have been more confused with *A. lonchitica* (Schlotheim).

"mixed," certain Radstockian forms are rarely, if ever, found in the division, while this is also true of a large number of Yorkian species. It is, however, too early to give a list of those Radstockian and Yorkian forms which are not found in the Staffordian. Nevertheless, it is possible to make a considerable advance in defining the Staffordian flora, by pointing out that it contains positive elements which at once distinguish it from the divisions above and below, namely *Linopteris münsteri* (Eichwald) and *L. obliqua* (Bunbury). Other species which occur more or less commonly in the division are *Sphenopteris neuropteroides*, *Neuropteris tenuifolia* (in the basal beds), *N. ovata*, *N. flexuosa*, *N. rarinervis*, *N. scheuchzeri*, *N. pseudogigantea*,[1] *Alethopteris serli-grandini*, *Mariopteris latifolia*, *M. nervosa*, *Sphenopteris striata*, *Sphenophyllum majus* and *S. emarginatum*.

The Yorkian Series of Yorkshire may be divided at the Silkstone Coal into a Lower and an Upper division. The Lower Yorkian is distinguished by a preponderance of *Alethopteris lonchitica* and *Neuropteris gigantea* (typical form), while *Neuropteris obliqua* though also having its maximum development in the division, is less characteristic. Occasional examples of the plants characterising the underlying Lanarkian occur, but are unknown from the Upper Yorkian, i.e. *Neuropteris schlehani*, *Sphenopteris hœninghausi*, *Sigillaria elegans*, etc. The Upper Yorkian can be recognised by the common occurrence of *Neuropteris tenuifolia* and *Sphenophyllum myriophyllum*, while the form known as *Neuropteris pseudogigantea* is found. *Lonchopteris bricei*, though rare, is confined to the division. *Neuropteris grangeri*, *N. microphylla*, *Sigillaria elongata* and *S. scutellata* are at their maximum, while *Sphenophyllum majus* does not occur in the Lower Yorkian. *Alethopteris davreuxi* may, later, prove to be a form characteristic of the Upper Yorkian.

The chief diagnostic species of the major Coal Measure divisions are summarised in the table (pp. 112 and 113). Many of these plants have been fully described and figured by

[1] Although *N. pseudogigantea* cannot be regarded as being specifically distinct from *N. gigantea*, the form is certainly commoner on higher horizons.

Series.	Division (Group).	Dividing Line (Type Area).	Characteristic Plants.
RADSTOCKIAN	Radstock	Base of Radstock Series (Somerset)	Cyatheites-Pecopterids
	Farrington	Base of Farrington Series (Somerset)	
STAFFORDIAN	(To be subdivided)	Chalky Mine Ironstone (N. Staffordshire)	*Linopteris obliqua*; *L. münsteri*
YORKIAN	Upper	Silkstone Coal (Yorkshire) forms base	*Neuropteris tenuifolia*; *Sphenophyllum myriophyllum*
	Lower	Better Bed (Yorkshire) forms base.	*Alethopteris lonchitica*; *Neuropteris gigantea*
LANARKIAN		Base of Coal Measures	*Neuropteris schlehani*, *Sphenopteris hœninghausi*, etc.

MILLSTONE GRIT (in part of Upper Carboniferous age)—Zone of *Pecopteris aspera*.

Dr. Kidston in his great Monograph "Fossil Plants of the Carboniferous Rocks of Great Britain,"[1] published by the Geological Survey and Museum. As yet, however, certain groups have not been treated in this work. These include *Alethopteris*, *Neuropteris*, *Linopteris*, *Odontopteris*, *Lonchopteris* and all the genera included in the Lycopodiales, Sphenophyllales, Equisetales and Cordaitales. Practically all the species are figured and briefly described in the writer's "Coal Measure Plants."[2] It should be pointed out that the Westphalian (= Yorkian) plant divisions given in these works have recently been revised.[3]

[1] Kidston, R., "Fossil Plants of the Carboniferous Rocks of Great Britain," *Mem. Geol. Surv., Palæontology*, Vol. ii, 1923-25.

[2] Crookall, R., *Coal Measure Plants*, London, 1929.

[3] Crookall, R., "A Critical Revision of Kidston's Coal Measure Floras," *Proc. Roy. Phys. Soc. Edinb.*, Vol. xxii, 1931, p. 1; "The Supposed Lanarkian in Shropshire," *The Naturalist* for 1932, p. 37;

V. Vertical Range of Diagnostic Species.

As a number of the diagnostic species indicated above occur in more than one division of the Coal Measures, it is desirable to give an estimate of the frequency with which they occur. This is done below (R = Radstockian Series; S = Staffordian Series; Y = Yorkian Series; L = Lanarkian Series: 1-2 = very rare; 3-4 = fairly rare; 6-7 = fairly common; 8-10 = very common.

Lycopodiales				
Bothrodendron minutifolium (Boulay)	R—0	S—1	Y—6	L—1
,, *punctatum* L. and H.	R—0	S—0	Y—4	L—0
Lepidodendron aculeatum Sternb.	R—4	S—4	Y—9	L—5
,, *lycopodioides* Kidst.	R—0	S—3	Y—8	L—2
,, *obovatum* Sternb.	R—0	S—2	Y—9	L—4
,, *ophiurus* Brongt.	R—0	S—1	Y—10	L—3
,, *wortheni* Lesqx.	R—7	S—4	Y—?	L—?
Lepidophloios acerosus (L. and H.)[1]	R—0	S—1	Y—6	L—8
,, *laricinus* (Sternb.)	R—0	S—1	Y—6	L—2
Sigillaria cumulata Weiss	R—6	S—0	Y—0	L—0
,, *discophora* Koenig	R—1	S—1	Y—8	L—2
,, *elegans* (Sternb.)	R—0	S—0	Y—3	L—8
,, *elongata* Brongt.	R—0	S—1	Y—7	L—0
,, *mammillaris* Brongt.	R—0	S—2	Y—8	L—2
,, *rugosa* Brongt.	R—0	S—1	Y—8	L—0
,, *tessellata* Brongt.	R—1	S—3	Y—10	L—2
,, *scutellata* Brongt.	R—0	S—2	Y—8	L—3
Sphenophyllales				
Sphenophyllum amplum Kidst.	R—0	S—0	Y—0	L—4
,, *cuneifolium* (Sternb.)	R—0	S—1	Y—10	L—3
,, *emarginatum* Brongt.	R—10	S—7	Y—1	L—0
,, *majus* (Bronn)	R—1	S—3	Y—4	L—0
,, *myriophyllum* Crépin	R—0	S—1	Y—5	L—0
,, *saxifragæfolium* (Sternb.)	R—0	S—0	Y—7	L—2

"Coal Measure Floras," *Annals of Botany*, Vol. xlvi, 1932, p. 454: Dix, E., in *Rep. Proc. Fifth International Botanical Congress, Cambridge*, 1931, p. 490; *Geol. Mag.*, Vol. lxviii, 1931, p. 529.

[1] *L. acerosus* may be commoner in the Yorkian than in the Lanarkian of Scotland, but the reverse is true in South Wales.

DIAGNOSTIC SPECIES OF THE MAJOR DIVISIONS.

Group.	Radstockian.	Staffordian.	Yorkian.	Lanarkian.
LYCOPODIALES	*Lepidodendron worthení* *Sigillaria cumulata*		*Bothrodendron punctatum* *B. minutifolium* *Lepidophloios laricinus* *Lepidodendron aculeatum* *L. lycopodioides* *L. obovatum, L. ophiurus* *Sigillaria discophora* *S. elongata, S. mammillaris* *S. rugosa, S. tessellata* *S. scutellata*	*Lepidophloios acerosus* *Sigillaria elegans*
SPHENOPHYLLALES	*Sphenophyllum emarginatum*	*S. emarginatum* *S. majus*	*Sphenophyllum majus* *S. cuneifolium* *S. saxifragæfolium* *S. myriophyllum*	*Sphenophyllum amplum*
EQUISETALES	*Annularia sphenophylloides* *A. stellata*	*A. sphenophylloides* *A. stellata*	*Annularia galioides* *A. microphylla*	
PTERIDOSPERMÆ and FILICALES Pecopterideæ	*Acitheca polymorpha* *Asterotheca arborescens* *A. cyathea* *A. oreopteridia* *Ptychocarpus unitus*	Some Pecopterids	*Dactylotheca plumosa* *Eupecopteris volkmanni* *Asterotheca miltoni*	

Sphenopterideæ	*Sphenopteris macilenta* *S. neuropteroides*	*S. neuropteroides* *S. striata* *Mariopteris latifolia* *M. nervosa*	*Sphenopteris dilatata* *S. footneri, S. laurenti* *S. marrati, S. sauveuri* *S. striata, S. trifoliolata* *S. trigonophylla* *Diplotmema furcatum* *Urnatopteris tenella* *Mariopteris nervosa* *Corynepteris coralloides* *C. sternbergi*	*Sphenopteris hœninghausi* *S. bæumleri* *Mariopteris acuta*
Alethopterideæ	*Alethopteris serli-grandini*	*A. serli-grandini*	*Alethopteris lonchitica* *A. decurrens* *Lonchopteris rugosa*	
Neuropterideæ	*Neuropteris ovata* *N. flexuosa* *N. macrophylla* *N. rarinervis* *N. scheuchzeri* *Odontopteris lindleyana*	*Linopteris münsteri* *L. obliqua* *Neuropteris tenuifolia* *N. ovata* *N. flexuosa*	*Neuropteris heterophylla* *N. gigantea, N. obliqua* *N. tenuifolia*	*Neuropteris schlehani*
CORDAITALES	*Poacordaites microstachys* *Cordaites angulosostriatus*		*Cordaites principalis* *C. borassifolius* *Dorycordaites palmæformis*	*Cordaites principalis*

EQUISETALES	
Annularia galioides (L. and H.)	R—0 ; S—0 ; Y—3 ; L—0
,, *microphylla* Sauv.	R—0 ; S—1 ; Y—2 ; L—0
,, *sphenophylloides* (Zenk.)	R—7 ; S—3 ; Y—1 ; L—0
,, *stellata* (Schl.)	R—10 ; S—3 ; Y—1 ; L—0
PTERIDOSPERMEÆ and FILICALES	
Pecopterideæ	
Acitheca polymorpha (Brongt.)	R—5 ; S—1 ; Y—0 ; L—0
Asterotheca arborescens (Schl.)	R—6 ; S—3 ; Y—0 ; L—0
,, *cyathea* (Schl.)	R—6 ; S—3 ; Y—0 ; L—0
,, *miltoni*	R—0 ; S ? 1 ; Y—10 ; L—0
,, *oreopteridia* (Schl.)	R—7 ; S—2 ; Y—0 ; L—0
Dactylotheca plumosa (Artis)	R—0 ; S—2 ; Y—10 ; L—1
Eupecopteris volkmanni (Sauv.)	R—0 ; S—1 ; Y—6 ; L—0
Ptychocarpus unitus (Brongt.)	R—8 ; S—3 ; Y—0 ; L—0
Sphenopterideæ	
Sphenopteris bœumleri Andrae	R—0 ; S—0 ; Y—0 ; L—3
,, *dilatata* L. and H.	R—0 ; S—1 ; Y—6 ; L—0
,, *footneri* Marrat	R—0 ; S—0 ; Y—4 ; L—0
,, *hœninghausi* Brongt.	R—0 ; S—0 ; Y—1 ; L—8
,, *laurenti* Andrae	R—0 ; S—1 ; Y—6 ; L—2
,, *macilenta* L. and H.	R—7 ; S—0 ; Y—1 ; L—0
,, *marrati* Kidst	R—0 ; S—1 ; Y—3 ; L—0
,, *neuropteroides* (Boul.)	R—7 ; S—3 ; Y—0 ; L—0
,, *sauveuri* Crépin	R—0 ; S—1 ; Y—7 ; L—0
,, *striata* Gothan	R—0 ; S—4 ; Y—9 ; L—4
,, *trifoliolata* (Artis)	R—0 ; S—0 ; Y—7 ; L—0
,, *trigonophylla* Behrend	R—0 ; S—0 ; Y—2 ; L—0
Corynepteris coralloides (Gutb.)	R—0 ; S—1 ; Y—6 ; L—0
,, *Sternbergi* Ett.	R—0 ; S—1 ; Y—4 ; L—0
Diplotmema furcatum (Brongt.)	R—0 ; S—0 ; Y—7 ; L—2
Urnatopteris tenella (Brongt.)	R—0 ; S—0 ; Y—6 ; L—2
Mariopteris acuta (Brongt.)	R—0 ; S—0 ; Y—3 ; L—8
,, *nervosa* (Brongt.)	R—0 ; S—5 ; Y—10 ; L—7
,, *latifolia* (Brongt.)	R—0 ; S—5 ; Y—2 ; L—0
ALETHOPTERIDEÆ	
Alethopteris decurrens (Artis)	R—0 ; S—1 ; Y—7 ; L—2
,, *lonchitica* (Schl.)	R—0 ; S—1 ; Y—10 ; L—4
,, *serli-grandini* (Bgt.)	R—10 ; S—6 ; Y—3 ; L—1
,, *valida* (Boulay)	R—0 ; S—0 ; Y—3 ; L—1
Lonchopteris rugosa Brongt.	R—0 ; S—0 ; Y—3 ; L—0
Neuropterideæ	
Linopteris obliqua (Bunbury)	R—0 ; S—8 ; Y—2 ; L—0
,, *münsteri* (Eichwald)	R—1 ; S—8 ; Y—1 ; L—0
Neuropteris flexuosa Sternb.	R—10 ; S—7 ; Y—0 ; L—0
,, *gigantea* Sternb.	R—0 ; S—3 ; Y—10 ; L—3
,, *heterophylla* Brongt.	R—1 ; S—2 ; Y—10 ; L—4
,, *macrophylla* Brongt.	R—9 ; S—3 ; Y—0 ; L—0
,, *obliqua* Brongt.	R—0 ; S—1 ; Y—8 ; L—0

Neuropteris ovata Hoff. . .	R—9 ; S—8 ; Y—1 ; L—0
,, *rarinervis* Bunb. .	R—9 ; S—8 ; Y—3 ; L—0
,, *scheuchzeri* Hoffm. .	R—10 ; S—10 ; Y—4 ; L—1
,, *schlehani* Stur . .	R—0 ; S—0 ; Y—2 ; L—8
,, *tenuifolia* (Schl.) .	R—0 ; S—6 ; Y—10 ; L—0
Odontopteris lindleyana Sternb. .	R—4 ; S—2 ; Y—0 ; L—0
CORDAITALES	
Cordaites angulosostriatus G'E. .	R—9 ; S—4 ; Y—0 ; L—0
,, *borassifolius* (Sternb.) .	R—1 ; S—2 ; Y—6 ; L—0
,, *principalis* (Germ.) . .	R—0 ; S—3 ; Y—9 ; L—6
Dorycordaites palmæformis (Goepp.)	R—1 ; S—2 ; Y—5 ; L—0
Poacordaites microstachys (Gold.) .	R—2 ; S—1 ; Y—0 ; L—0

VI. DIVIDING LINES BETWEEN THE MAJOR DIVISIONS.

The base of the Radstockian Series in Somerset is at the Farrington Series, and is probably the Hughes Vein of South Wales.

The base of the Staffordian Series in Somerset is taken as the New Rock Series: in South Wales it is the No. 3 Rhondda Seam of Glamorganshire and the Lower Pinchin Seam of Merthyr. The Shafton Marine Band is taken as the base in Yorkshire,[1] and the Ardwick Group in Lancashire. Miss Dix has drawn the base in North Staffordshire at just below the Chalky Mine. In South Staffordshire the base of the Staffordian is at the top of the Hamstead and Sandwell Park Marine Band (i.e., 75 feet below the base of the Etruria Marl Group).

The base of the Yorkian of Somerset must be taken as in the Vobster Series, in South Wales (Merthyr area) at the Cnapiog Seam, in Yorkshire at the Better Bed [1] and in Lancashire at the Arley Mine. In the Scottish coalfields it is represented by the Mill or Auchingane coal of Stirlingshire and its equivalents.

The writer has to thank the Director of the Geological Survey of Great Britain for permission not only to publish this paper but also to use a number of Kidston's photographs of fossil plants in the plates.

[1] Dr. D. A. Wray, in MS.

PLATE I.

FOSSIL PLANTS OF NO GENERAL STRATIGRAPHICAL VALUE.

FIG. 1.—*Lepidophyllum intermedium* Lindley and Hutton (× 1) (R. K.). Occurrence: Bracts and leaves of this general type are found throughout the Coal Measures and are common fossils. Description: These fossils vary greatly in width and length, but always have a single central vein. Other bracts are shaped like arrow-heads.

FIG. 2.—*Stigmaria ficoides* (Sternberg) (× ¼) (R. K.). Occurrence: Very common at all levels in the Coal Measures. Description: Casts are cylindrical, and bear numerous circular marks (the points at which rootlets were given off: the rootlets can often be seen, ribbon-like, as in the figure). At the centre of each circular scar is a point (marking the position of the vein which passed into the rootlet).

FIG. 3.—*Calamites carinatus* Sternberg (× 1) (R. C.). Occurrence: Common in all divisions. Description: There is a large opening of the branch-scar (top right-hand side of figure).

FIG. 4.—*Pinnularia columnaris* (Artis) (× 1) (R. K.). Occurrence: Very common. Found in all divisions of the Coal Measures. Description: These remains can be readily recognised as representing roots and rootlets. Sometimes the rootlets only are preserved (*P. capillacea*).

FIG. 5.—*Artisia transversa* (Artis) (× 1) (R. K.). Occurrence: Common in all divisions of the Coal Measures. Description: Cylindrical casts with constrictions at intervals. Casts of the pith-cavity of stems of *Cordaites*.

FIG. 6.—*Calamites suckowi* Brongniart (× 1) (R. K.). Occurrence: Very common and widely spread in all divisions of the Coal Measures. Description: The nodes of this form of pith cast, belonging to the Equisetales, are not constricted. The ribs are straight (contrast the undulating ribs often, though not always, seen in *C. undulatus* Sternberg, a Yorkian and Lanarkian species) and form a bluntly rounded angle at the nodes. The upper tubercles are oval or circular. Branch-scars are usually absent.

PLATE II.

FOSSIL PLANTS OF NO GENERAL STRATIGRAPHICAL VALUE.

FIG. 1.—*Calamites undulatus* Sternberg (× 1). Photograph by R. Kidston (Kidston Collection, No. 4040). Occurrence: Occurs in all divisions of the Coal Measures though more com-

monly in the lower two. Description: The tops of the ribs form almost a right-angle and the upper surface of the ribs is cross-hatched.

FIG. 2.—*Halonia tortuosa* Lindley and Hutton (× ½). Photograph by R. Kidston (Kidston Collection, No. 2176). Occurrence: Yorkian and Lanarkian. Description: see text, p. 96.

FIG. 3.—*Asterophyllites equisetiformis* (Schlotheim) (× 1). Photograph by R. Kidston. Occurrence: all divisions. No definite maximum. Description: Photograph shows cones of the species.

FIG. 4.—*Lepidocystis* (× 1). Photograph by R. Kidston (Collection of Museum of Practical Geology, No. 50011). Occurrence: All divisions. Description: See text, p. 100.

FIG. 5.—*Spiropteris* (× 2). Photograph by R. Kidston (Collection of Museum of Practical Geology, No. 50012). Occurrence: All divisions. Description, see text, p. 95.

PLATE III.

RADSTOCKIAN SPECIES.

FIG. 1.—*Annularia sphenophylloides* (Zenker) (× 1) (R. C.). Occurrence: Common in the Radstockian; fairly common in the Staffordian. Description: The leaves are spoon-shaped, narrow at the base, broad towards the apex and terminating in a more or less sharp point.

FIG. 2.—*Annularia stellata* (Schlotheim) (× 1) (R. K.). Occurrence: Very common in the Radstockian; fairly rare in the Staffordian. Description: The widest part of the leaf occurs about two-thirds from the base. The leaf tapers to a blunt point, but less quickly than in the common Yorkian and Lanarkian species *A. radiata* Brongniart. In the latter species the leaf is sharply pointed.

FIG. 3.—*Alethopteris serli-grandini* Brongniart (× 1) (R. K.). Occurrence: Very common in the Radstockian, less so in the Staffordian. Only very occasionally found in the Yorkian. Description: The leaflets differ from the common Yorkian *A. lonchitica* in being swollen in the middle. The lateral veinlets are also finer, closer and less divided.

FIG. 4.—*Neuropteris scheuchzeri* Hoffmann (× 1) (R. K.). Occurrence: very common in the Radstockian and Staffordian. Description: Easily recognised by the presence of hairs, about ¼ inch long, in addition to the numerous veins. The leaflets are bluntly pointed at the apex. The leaves often bear two small rounded leaflets at the base.

FIG. 5.—*Neuropteris flexuosa* Sternberg (× 1) (R. K.). Occurrence: Very common in the Radstockian: rarer in the Staffordian.

Description: The leaflets are attached to the rachis by a broad base and about 3 veins abut the margin per mm. The terminal leaflet is large and free (in the similar, though smaller *N. ovata* Hoffmann, having a similar general range though probably appearing earlier, it is small and united to the adjacent leaflet). The veins are clearly marked. (See Crookall, R., *Proc. Cotteswold Nat. F. C.*, Vol. xxiii, 1930, p. 240, where several species of *Neuropteris* are compared.)

FIG. 6.—*Acitheca polymorpha* (Brongniart) (× 1) (R. K.). Occurrence: This is a very typical Radstockian Pecopterid, though it is not common. It has been found, very rarely, in the Staffordian, but not in the divisions below. Description: The leaflets are devoid of hairs (such as occur on *Asterotheca abbreviata* (Brongniart)) and the forking lateral veinlets meet the margin of the leaflet almost at right angles.

FIG. 7.—*Ptychocarpus unitus* (Brongniart) (× 1) (R. K.). Occurrence: Very common in the Radstockian, rather rare in the Staffordian: unknown from lower divisions. Description: In this Pecopterid the leaflets are somewhat united to each other. The venation is very characteristic, the lateral veinlets being bow-shaped and never divided.

PLATE IV.

RADSTOCKIAN SPECIES.

FIG. 1.—*Asterotheca arborescens* (Schlotheim) (× 1). Photograph by R. Kidston (Kidston Collection, No. 452). Occurrence: Common. Description: Veinlets are never divided.

FIG. 2.—*Neuropteris rarinervis* Bunbury (× 2). Photograph by R. Kidston (Kidston Collection, No. 559). Occurrence: Common (also occurs in Staffordian). Description: Leaflets enlarged at base: veinlets few, strong, slightly arched.

FIG. 3.—*Sphenophyllum emarginatum* Brongniart (× 1). Photograph by W. Hemingway. Occurrence: Common (also occurs in Staffordian). Description: The apical teeth are rounded.

FIG. 4.—*Sphenopteris macilenta* Lindley and Hutton (× 1). Photograph by R. Kidston (Kidston Collection, No. 230). Occurrence: fairly common. Description: the leaflets are lobed, the lobes being bluntly rounded.

FIG. 5.—*Odontopteris lindleyana* Sternberg (× 1). Photograph by R. Kidston (Kidston Collection, No. 4078). Occurrence: Only common locally. Description: Leaflets are decurrent on the rachis and the latter gives off veins which enter the bases of the leaves.

FIG. 6.—*Sphenopteris neuropteroides* (Boulay) (× 1). Photograph by R. Kidston (Kidston Collection, No. 228). Occurrence: Common. Description: The leaflets are almost square, and are not stalked (contrast *S. striata*).

PLATE V.

STAFFORDIAN SPECIES.

FIG. 1.—*Mariopteris latifolia* (Brongniart) (× 1). Photograph by R. Kidston. Occurrence: Fairly common. Description: The blunt, forward-directed lobes are closer than in *M. beneckei* Huth.

FIG. 2.—*Mariopteris latifolia* (Brongniart) (× 2). The same specimen, enlarged to show venation.

FIG. 3.—*Linopteris obliqua* (Bunbury) (× 2). Photograph by R. Kidston (Collection of Museum of Practical Geology, No. 50013). Occurrence: Fairly common. Description: Shape of leaflet as in *Neuropteris gigantea*, but the veins form a network.

FIG. 4.—*Linopteris obliqua* (Bunbury) (× 1). Photograph by R. Kidston (Kidston Collection, No. 4204).

FIG. 5.—*Linopteris münsteri* (Eichwald) (× 2). Photograph by R. Kidston. Occurrence: Very common and widespread. Description: Shape of leaflets as in *Neuropteris heterophylla*, but the veins form a network. The meshes of the network are larger than in *L. obliqua*.

FIG. 6.—*Neuropteris ovata* (Hoffmann) (× 1). Photograph by R. Kidston (Kidston Collection, No. 302). Occurrence: Fairly common: also in Radstockian. Description: Smaller than *N. flexuosa*. Terminal pinnule is united to the uppermost lateral pinnule.

FIG. 7.—*Asterotheca oreopteridia* (Schlotheim) (× 3). Photograph by R. Kidston (Kidston Collection, No. 508). Occurrence: Much commoner in the Radstockian than in the Staffordian. The species is included to illustrate the occurrence of the Cyatheites-Pecopterids in the Staffordian. Description: The veins are like tuning forks in shape.

FIG. 8.—*Sphenophyllum majus* (Bronn) (× 1). Photograph by R. Kidston (Kidston Collection, No. 2701). Occurrence: Fairly rare: also in Yorkian. Description: The teeth are sharp (contrast *S. emarginatum*) and two veins enter each leaflet.

PLATE VI.

YORKIAN SPECIES.

FIG. 1.—*Dorycordaites palmæformis* (Goeppert) (× 1). Photograph by R. Kidston (Kidston Collection, No. 2907). Occurrence: Fairly frequent in Yorkian, unknown in Lanarkian. Description: The apex of the leaf (shown) is sharply pointed in this species.

FIG. 2.—*Sigillaria rugosa* Brongniart (× 1). Photograph by R. Kidston (Kidston Collection, No. 2852). Occurrence: Very typical of and common in the Yorkian. Description: Plume-like lines occur above the leaf-scar.

FIG. 3.—*Alethopteris valida* Boulay (× 1). Photograph by R. Kidston. Occurrence: Fairly rare: not known above Yorkian. Description: The veins are only slightly flexuous. The shape of the leaflets is distinctive.

FIG. 4.—*Bothrodendron minutifolium* (Boulay) (× 2). Photograph by R. Kidston (Kidston Collection, No. 1845). Occurrence: Fairly common in the Upper Yorkian. Description: The wrinkles on the stem are parallel to the longer axis of the leaf-scar (in *B. punctatum* they are vertical).

FIG. 5.—*Lepidodendron lycopodioides* Kidston (? Sternberg) (× 1). Photograph by R. Kidston (Kidston Collection, No. 2080). Occurrence: Common, chiefly in Yorkian. Description: The leaf-scars are represented merely by an angular slit, as shown.

FIG. 6.—*Neuropteris obliqua* Brongniart (× 1). Photograph by R. Kidston (Kidston Collection, No. 1137). Occurrence: Common in Yorkian, especially in lower portion. Description: The lower margin of the leaflet tends to be oblique and decurrent down the rachis.

FIG. 7.—*Neuropteris tenuifolia* (Schlotheim) (× 1). Photograph by R. Kidston (Kidston Collection, No. 3629). Occurrence: Chiefly in Upper Yorkian. Description: Margins of pinnules slightly taper towards the apex. The end pinnule is larger than the others.

FIG. 8.—*Neuropteris heterophylla* Brongniart (× 2). Photograph by R. Kidston (Kidston Collection, No. 4002). Occurrence: Very common in Yorkian. Description: Leaflets rounded, veins clear, fewer than in *N. gigantea*.

PLATE VII.

YORKIAN SPECIES.

FIG. 1.—*Mariopteris nervosa* (Brongniart) (× 1) (R. K.). Occurrence: Very common and widespread in Yorkian; less common in Staffordian and Lanarkian. Description: Compared with *M. muricata* (Schlotheim), the leaflets are more triangular and their bases nearly always confluent, while lobing is rare or absent.

FIG. 2.—*Neuropteris gigantea* Sternberg (× 1) (R. K.). Occurrence: Very common and widespread in Lower Yorkian: also occurs in Staffordian and Lanarkian. Description: Leaflets are often found isolated. Terminal leaflets are smaller than the others. The veinlets are very closely placed.

FIG. 3.—*Sphenophyllum saxifragæfolium* (Sternberg) (× 1) (R. C.). Occurrence: Very common and widespread throughout Yorkian; rare in Lanarkian, unknown in Staffordian. Description: The lateral edges of the leaflets are concave outwards. The apex is divided by 1, 3 or 5 clefts.

FIG. 4.—*Lepidodendron ophiurus* Brongniart (× 1). Photograph by R. Kidston (Kidston Collection, No. 1018). Occurrence: Common in Yorkian; rare elsewhere. Description: Leafy twigs of the species are shown. The leaf-scars are about two-thirds up the cushion. The keel is not crossed by transverse lines.

FIG. 5.—*Sphenophyllum cuneifolium* (Sternberg) (× 1) (R. K.). Occurrence: Very common and widespread in Yorkian, rare in Staffordian and Lanarkian. Description: the edges of the leaves are straight or, more often, slightly concave outwards. The apices have six to twelve sharp triangular teeth.

FIG. 6.—*Alethopteris decurrens* (Artis) (× 2) (R. K.). Occurrence: Common and widespread. Description: this is a more linear form than *A. lonchitica.* See also remarks on Explanation to Plate VIII, Fig. 8—under *Neuropteris rectinervis.*

FIG. 7.—*Dactylotheca plumosa* (Artis) var. *delicatula* Brongniart (× 1) (R. K.) Occurrence: Very common and widespread in Yorkian; rare in Staffordian and Lanarkian. Description: This is a small form of the plant. The triangular leaflets are toothed. In the smaller leaflets the veinlets are undivided, but in the larger ones they fork once.

FIG. 8.—*Sphenopteris striata* Gothan (× 2) (R. K.). Occurrence: Very common and widespread in Yorkian; rarer in Staffordian and Lanarkian. Description: The leaflets are distinctly stalked and their surface bears fine striæ. In the Radstockian *N. neuropteroides* (Boulay) the leaflets are square and not stalked.

FIG. 9.—*Lonchopteris rugosa* Brongniart (× 1) (R. K.). Occurrence: Rather rare, but, when found, very typical of the Yorkian Series. Description: The leaf is shaped like that of the much commoner *Alethopteris,* but in *Lonchopteris* the veins form a network.

FIG. 10.—*Lepidophloios laricinus* Sternberg (× 1) (R. K.). Occurrence: Common and widespread in Yorkian: rare in Staffordian and Lanarkian. Description: Leaf-scars much broader than long. See remarks on Explanation to Plate VIII, Fig. 7—*L. acerosus.*

PLATE VIII.

LANARKIAN SPECIES.

FIG. 1.—*Sphenopteris hœninghausi* Brongniart (× 1) (R. K.). Occurrence: Fairly common, but often of local occurrence, as the plants probably grew in dense masses. Description: The surface of the stem and leaves bears small spines (? or glandular hairs) and on the larger stems can be seen rhomboidal markings with a dot in the centre (the base of a spine). The leaflets were very convex and small (1-3 mm.). They occur alternately on the rachis and are lobed, especially the lower ones.

FIG. 2.—*Mariopteris acuta* (Brongniart) (× 1) (R. K.). Occurrence: Fairly common. Description: *M. acuta* is distinguished from *M. muricata* (Schlotheim) in that the marginal teeth of the leaflets remain close to the border (whereas in *M. muricata* they point outwards). The leaflets are also longer and narrower and more distinctly cut up than in *M. muricata.*

FIG. 3.—*Sphenophyllum amplum* Kidston pro sp. (× 1) (R. K.). Occurrence: Fairly rare. Description: *S. amplum* was originally described as a form of *S. cuneifolium* (Sternberg), because the leaves are narrow and wedge-shaped and bear sharp teeth (as in that species). The leaves measure 14-17 mm. or so long. In *S. cuneifolium* they are 8-10 mm. long. There is a marked tendency to curve in the leaves of *S. amplum.*

FIG. 4.—*Sphenopteris bæumleri* Andrae (× 2) (R. K.). Occurrence: Fairly rare. Description: *S. bæumleri*, like *S. hœninghausi*, belongs to the *Lyginodendron* group. As in that species, the stems bear rhomboidal markings from the centre of which arose small spines. Spines do not, however, occur in the leaves of *S. bæumleri.* The latter occur alternately on the rachis and are broadly oval. The lower leaflets are contracted at the base and bear rounded lobes; the upper have a broad base and are entire, though their margins may be crenulate. The basal posterior pinnule is larger than the corresponding anterior leaflet. A central vein is seen, but the forking lateral veinlets are generally indistinct.

FIG. 5.—*Neuropteris schlehani* Stur (× 1) (R. K.). Occurrence: frequent. Description: The leaflets are from 8-30 mm. long and 4-8 mm. broad and are not decurrent on the rachis. The apical leaflet is long and linear.

FIG. 6.—*Sigillaria elegans* Brongniart (× 1) (R. K.). Occurrence: Common. Description: The longitudinal furrows are much more distinctly zig-zag than in the Yorkian and Lanarkian *S. scutellata* Brongniart and *S. tessellata* Brongniart. The leaf-scars are much closer together than in *S. mammillaris*, a Yorkian form. and no transverse markings occur below them.

FIG. 7.—*Lepidophloios acerosus* (Lindley and Hutton) (× 2) (R. K.). Occurrence: Fairly common. Description: In this species there is a strong vertical keel on each leaf-cushion. A keel is absent from, or only faintly marked in *L. laricinus.*

FIG. 8.—*Neuropteris schlehani* Stur (× 1) (R. K.). Occurrence: Fairly common. Description: This (the *N. rectinervis*) form of *N. schlehani* has resemblances to *Alethopteris lonchitica*, but in the latter the leaflets are decurrent on the rachis, while in the former their bases are rounded. The apex of the leaflets is blunt. The lateral veinlets are numerous. They curve gently from the midrib and then pass, almost at right angles, to the margin, generally forking once, though occasionally twice. See p. 107.

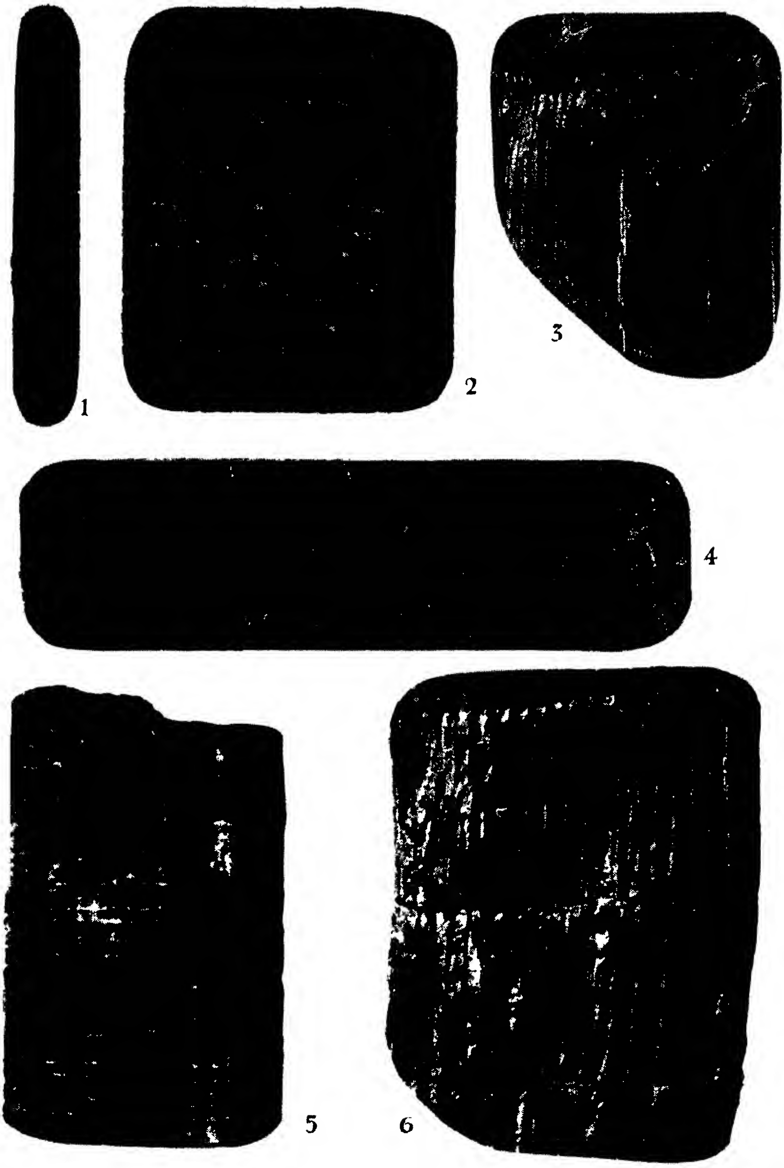

PLATE I.

Non-Zonal Fossil Plants.

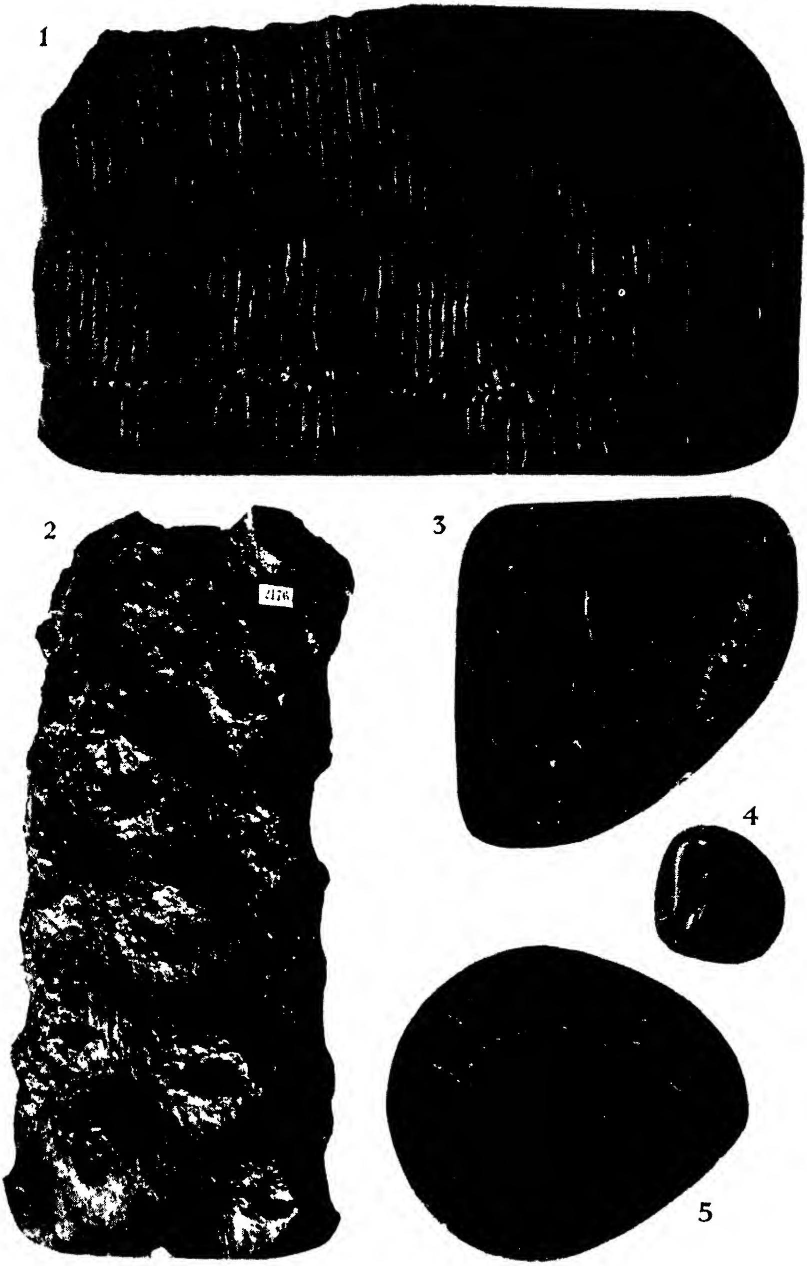

Plate II.

Non-Zonal Fossil Plants.

PLATE III.

Radstockian Species.

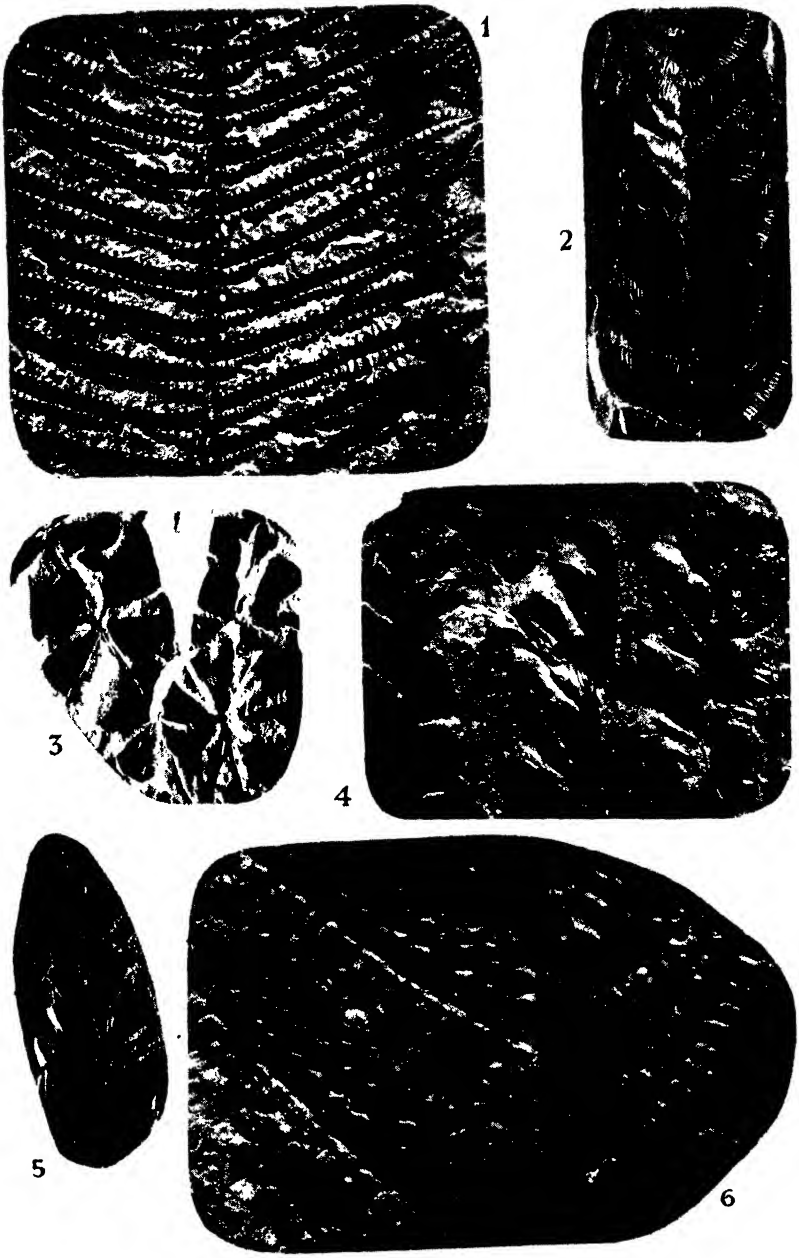

PLATE IV.

Radstockian Species.

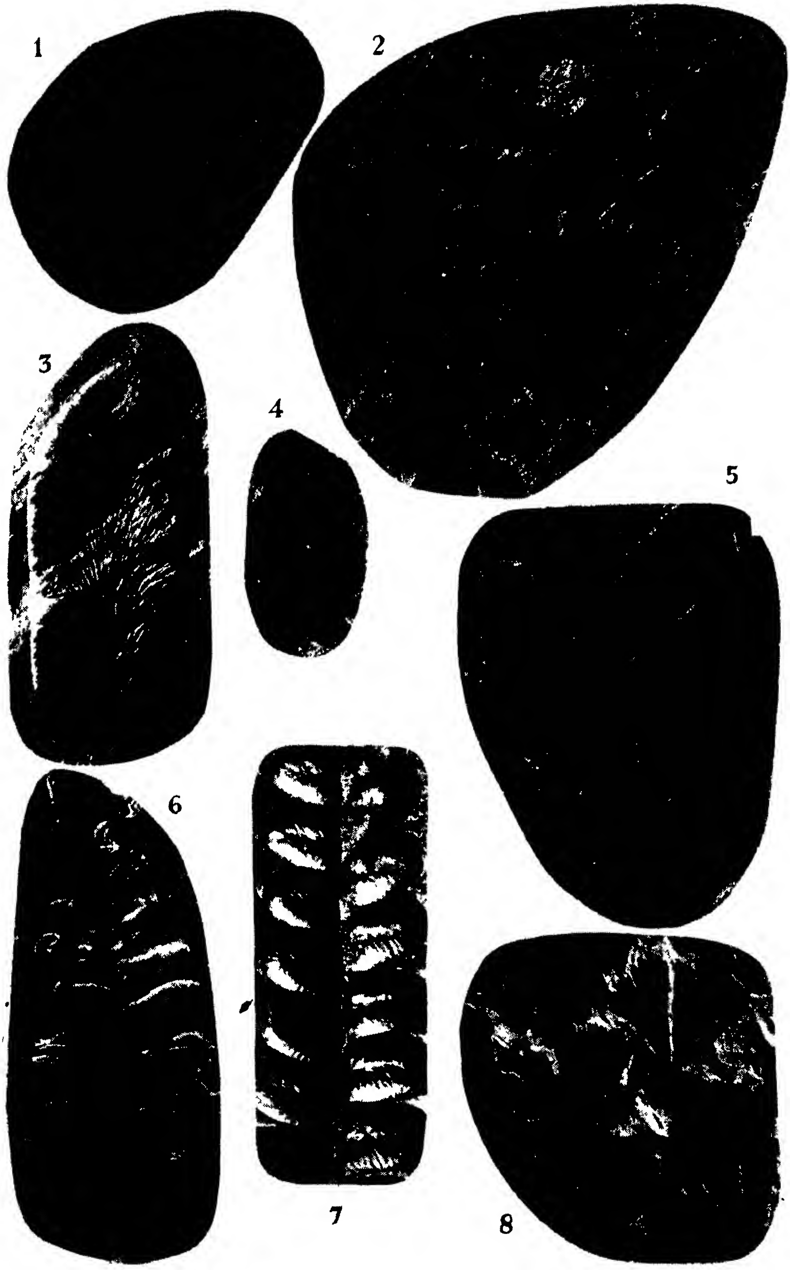

PLATE V.

Staffordian Species.

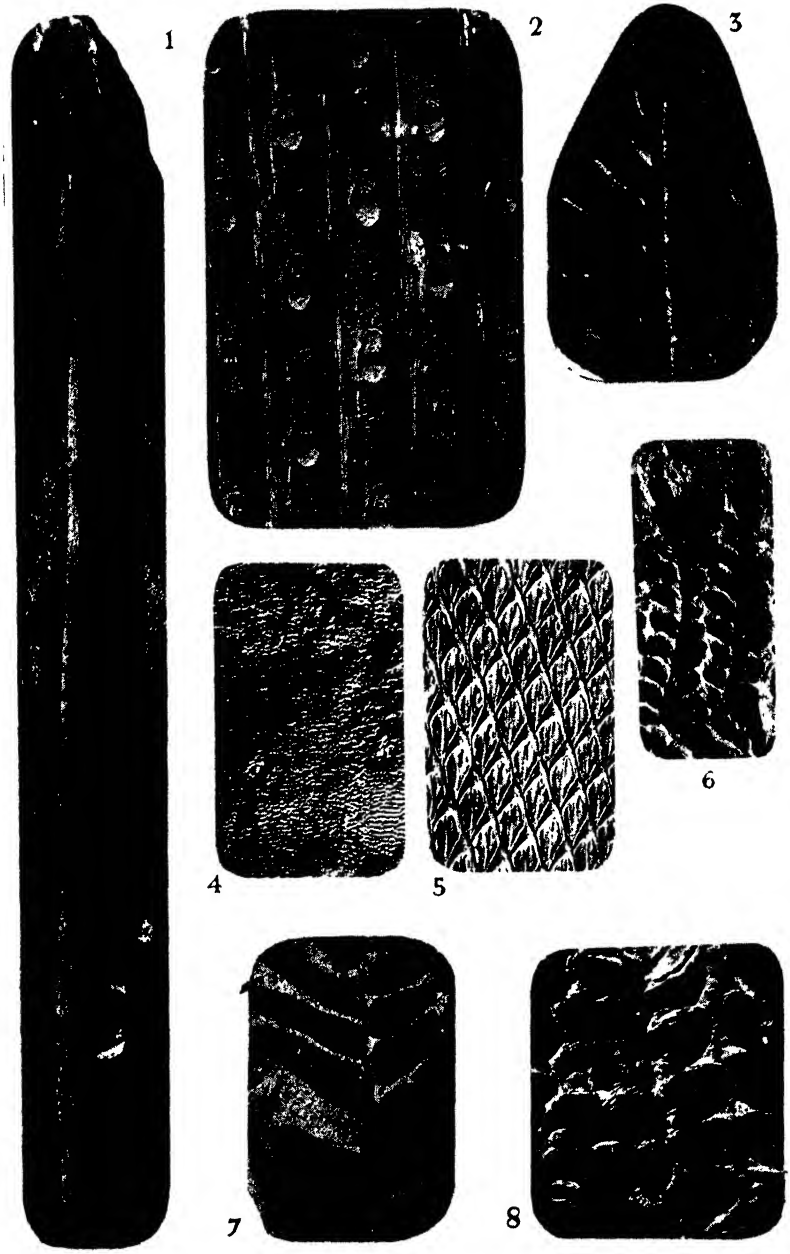

PLATE VI.

Yorkian Species.

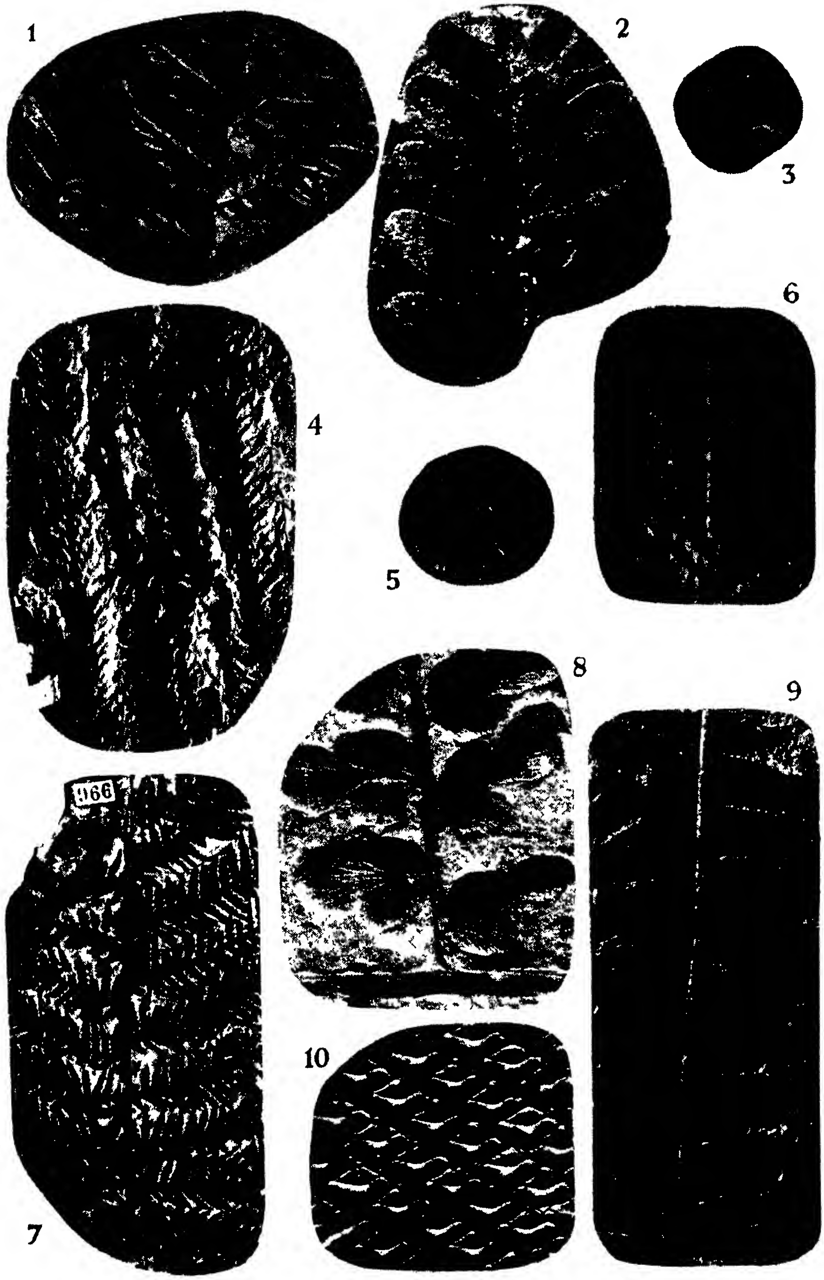

PLATE VII.

Yorkian Species.

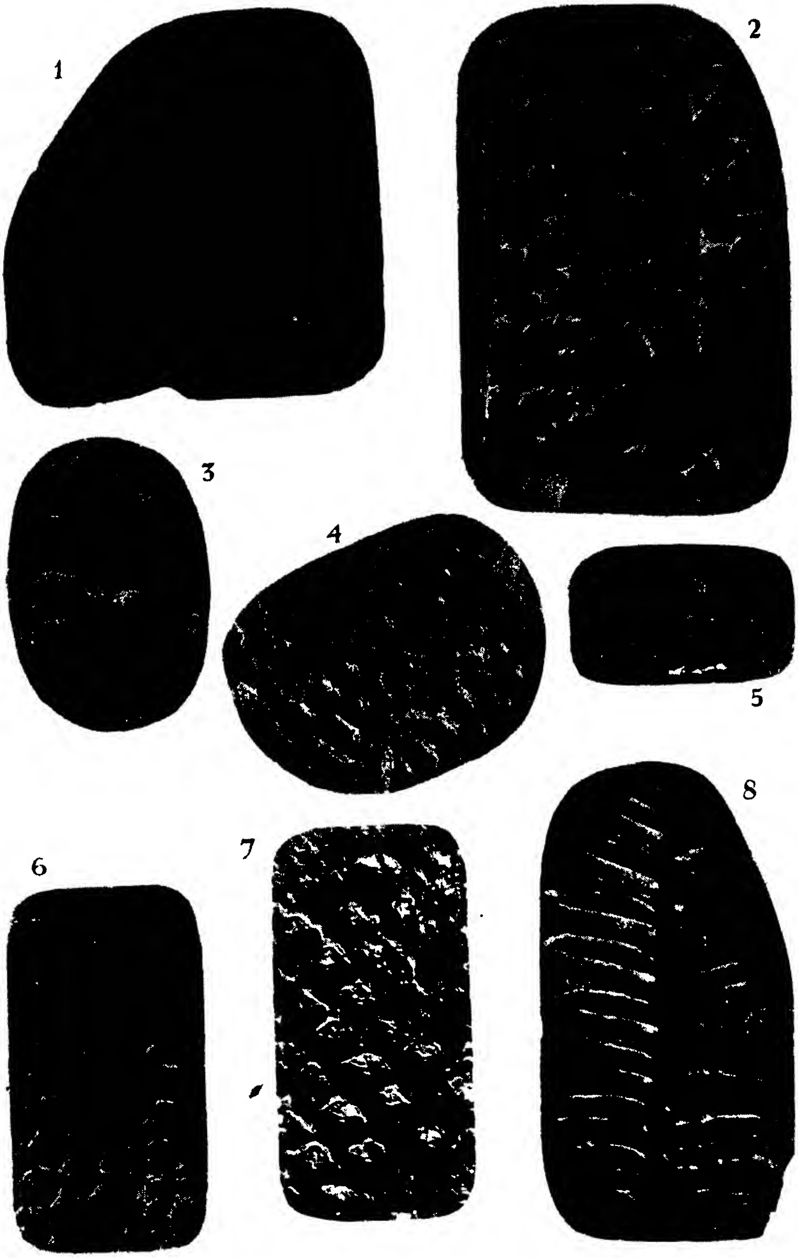

PLATE VIII.

Lanarkian Species.

PROCEEDINGS OF THE MANCHESTER LITERARY AND PHILOSOPHICAL SOCIETY.

Obituaries.

Mr. Thomas Alva Edison, who died on 18th October, 1931, at the age of 84, was our oldest honorary member, having been elected in 1892. By that date he had established his reputation as an inventor, and had given to the world a new form of dynamo, duplex telegraphy (to be followed later by the quadruplex and sextuplex systems), the incandescent carbon filament lamp, the carbon telephone, the tasimeter, the mimeograph, and a number of other inventions, some of which did not fulfil expectations. This is not the place to recount the other achievements which have made his name immortal, but the Society has seldom or never been more successful in recognising at an early period the qualities of a man whose subsequent career was so brilliant. It is perhaps not generally known that he held three doctorates from American Universities, and that he was appointed by the French Government a Commander of the Legion of Honour.

C. L. B.

Charles Prestwich Scott, for fifty-seven years Editor of the *Manchester Guardian*, died at his home in Fallowfield, Manchester, on New Year's Day, 1932. Mr. Scott was born at Bath in October, 1846. After a private education he went to Corpus Christi College, Oxford, and read for "Greats." He served for a year on the staff of the *Scotsman* before joining the staff of the *Manchester Guardian* in 1871. It was only a year later, at the age of 25, that he was appointed editor. For some years he concerned himself with the editorial organisation of the paper, while taking his share with others in the leading columns. He soon began to gather round him a brilliant company of colleagues, W. T. Arnold (grandson of Arnold of Rugby), C. E. Montague, and others. His first great move in policy was when he followed Gladstone in approval of Home Rule for Ireland. From this time, 1886, the *Manchester Guardian* threw off its Whiggism and became a Liberal force. About this time Mr. Scott came out into active

politics, and after several unsuccessful attempts, he was elected Member of Parliament for Leigh in 1895. He continued to sit in Parliament for ten years, all of which were spent in Opposition. At the time of the Boer War, Mr. Scott steered the paper through the most difficult years of its history. He took the unpopular side, and the paper remained uncompromisingly opposed to the South African War from its beginning to end. In 1905 Mr. Scott became sole owner of the *Manchester Guardian*. He was 60 years old, but the greatest period of his editorship was still to come. From this time he and the *Guardian* were indissolubly one. No branch of the paper escaped his criticism and scrutiny. The brilliant young men who continued to find their way to the editorial corridor were all under his vigilant and unquestioned authority. The period of the Great War was another time when the views expressed by the paper were contrary to much of popular opinion, but Mr. Scott never vacillated when once a policy had been firmly expressed. In 1921, the centenary year of the paper's founding, and the jubilee of his editorship, the world paid homage to the nature of his editorship. The King sent a message, and all the Conservative papers in the country recognised by public comment the honesty of their opponent. From the smaller countries of the world, whose friend he always was, came particularly warm tributes. A great congratulatory gathering was held in Manchester at which Lord Derby presided.

The negotiations for the Irish Treaty in this same year would never have reached a satisfactory conclusion if it had not been for Mr. Scott's part in them. He was the only man trusted on both sides, and was at Mr. Lloyd George's side during the critical stages. Later he did all he could, at the time of the first Labour Government, for the Labour and Liberal parties to work together. The spirit in which he discussed the General Strike in the columns of his paper in 1926 did much to restore sanity to politics. Among public events in his life at this time were his election to an honorary fellowship of Corpus Christi in 1923, and the celebration of his eightieth birthday in 1926 by the presentation of his bust by Epstein to the city of Manchester. In July, 1929, he retired from the editorship, but remained managing director, and the following year Manchester paid him the greatest honour it was hers to bestow. In April, 1930, he became a freeman of the city. He retained a lively interest in the affairs of the *Manchester Guardian* until his last illness.

It remains to add that the *Guardian* frequently sent reporters to the Society's meetings, and was always ready to assist in any way which would advance its reputation. In recognition of the services thus indirectly rendered, Mr. Scott was elected an honorary member in 1926.

Arthur Adamson, whose death took place suddenly at Levenshulme, Manchester, on January 5th, 1932, was born on March 16th, 1870. He was educated at the Central Board School, Manchester, and later at the Royal College of Science, London, where he obtained the Associateship Diploma with First Class Honours in Mechanics and Physics.

After a period of two years as Assistant-Demonstrator in Physics at the Royal College of Science, and a further year as Lecturer at the Science and Art and Technical School, Chester, he returned to Manchester, in 1894, as a teacher of Mathematics and Physics at the Central Board School. This post he held till 1899 when he joined the staff of the College of Technology where he subsequently became Lecturer in Physics, both in the College and in the Faculty of Technology of the University of Manchester. In 1912 he was awarded the degree of M.Sc.Tech., Manchester University.

Mr. Adamson was specially interested in Optics and contributed several papers on this subject to scientific journals. He was associated with the Applied Optics Courses of the College of Technology since their inception twenty-five years ago, being particularly responsible for the lectures in Physical and Technical Optics. In these he had ample opportunity of expounding some highly original methods of approach to special problems for which he became well known. It is to be regretted that he could not be persuaded to collect these methods for publication, all that he has left in this direction being in the form of instruments, e.g. a refractometer for the rapid determination of the refractive indices of liquids (made by Messrs. Baird & Tatlock, London), and an ingenious type of focimeter.

Mr. Adamson was a most genial teacher and colleague. His loss is keenly felt by staff and students alike.

He became a member of this Society on April 4th, 1911, and at the time of his death had just completed a paper entitled: "Empirical Formulæ for the Relation between the Temperature and Pressure of Saturated Vapour," which appears in the MEMOIRS.

H. L.

PROCEEDINGS.

COUNCIL MEETING, OCTOBER 6th, 1931.

Mr. W. A. DEER and Mr. S. R. NOCKOLDS were elected Student-Associate Members of the Society for the Session 1931-32.

GENERAL MEETING, OCTOBER 6th, 1931.

Mr. B. MOUAT JONES (*President*) in the Chair.

The following were elected Ordinary Members of the Society :

SYDNEY GOLDSTEIN, Lecturer, 25 Brunswick Road, Withington, Manchester.

WALTER FITZGERALD, Lecturer, The University, Manchester.

FRANCIS CARTER TOY, The Shirley Institute, Didsbury, Manchester.

ORDINARY MEETING, OCTOBER 6th, 1931.

Professor W. L. BRAGG, M.A., F.R.S., and Dr. G. N BURKHARDT, M.Sc., spoke on points of scientific interest discussed before the British Association at the recent meetings in London.

GENERAL MEETING, OCTOBER 20th, 1931.

Mr. B. MOUAT JONES (*President*) in the Chair.

The following were elected Ordinary Members of the Society :—

HARRY CROMWELL LAMB, Engineer, The Electricity Department, Dickinson Street, Manchester.

HAROLD MANDELBERG, M.A., Manufacturer, Oughtrington House, Lymm, Cheshire.

ORDINARY MEETING, OCTOBER 20th, 1931.

Mr. B. MOUAT JONES, D.S.O., M.A., delivered his Presidential Address, on :—

"The Scientist and the Historian: a Plea for Co-operation."

This address is printed in the MEMOIRS.

GENERAL MEETING, NOVEMBER 3rd, 1931.

Mr. B. MOUAT JONES (*President*) in the Chair.

The following were elected Ordinary Members of the Society :—

HUGH STOTT TAYLOR, Professor of Chemistry, The University, Manchester.

WILLIAM JOHN PUGH, O.B.E., D.Sc., Professor of Geology, The University, Manchester.

HERBERT GRAHAM CANNON, M.A., D.Sc., Professor of Zoology, The University, Manchester.

CECILIA MIREIO LEGGE, Assistant Keeper in the Manchester Museum, The University, Manchester.

ORDINARY MEETING, NOVEMBER 3rd, 1931.

Mr. A. ADAMSON, M.Sc. Tech., A.R.C.S., read a paper on :—

"Empirical Formulæ for the relation between the temperature and pressure of saturated vapours."

This paper is printed in the MEMOIRS.

Mr. GLYN OWEN, M.Sc., read a paper on :—

"Additive compounds of Nitroamines and Anilines."

This paper is printed in the MEMOIRS.

COUNCIL MEETING, NOVEMBER 17th, 1931.

Mr. H. BIRCHALL was elected a Student-Associate Member of the Society, for the Session 1931-32.

GENERAL MEETING, NOVEMBER 17th, 1931.

Mr. B. MOUAT JONES (*President*) in the Chair.

The following was elected an Ordinary Member of the Society :—

HENRY SYDNEY LAND, Research Chemist, 10 Ashlands, Ashton-on-Mersey, Cheshire.

ORDINARY MEETING, NOVEMBER 17th, 1931.

Mr. B. MOUAT JONES (*President*), in the Chair.

Professor F. C. Thompson, M.Sc., D.Met., read a paper on :—

"Michael Faraday as a Metallurgist."

Although in his own opinion, and in many later ones, the work of Faraday on steel led to no useful result, it is none the less a fact that this represented his first extensive research. In conjunction with Mr. James Stodart, F.R.S., a manufacturer of surgical instruments and cutlery, Faraday commenced work on steel, and the improvements which might be effected by the addition of other metals, certainly not later than 1819. From that time till 1824, despite the death in the meantime of his collaborator, the work proceeded. Three papers were published, and at least one of his results left a permanent impress on metallurgical nomenclature.

There can be very little doubt that the term "silver-steel," for a high carbon crucible steel which, in 99 per cent. of cases, contains no silver whatever, is the direct result of Faraday's own labours. First on a small scale in the laboratories of the Royal Institution, and later on a much more extensive one in

a Sheffield steel works, these special alloys were produced and examined.

Platinum, palladium, rhodium, osmium and iridium were the very precious metals employed. Gold and silver as less expensive materials were also introduced, whilst copper, tin, nickel, chromium and titanium complete the list of metals investigated. Wollaston supplied these additions with a lavishness which can create nothing but surprise.

Just over a year ago samples of some of the steels actually produced by Faraday came into the hands of Sir Robert Hadfield with the concurrence of the Management Board of the Royal Institution, and a report on their analyses, structures and properties has now added enormously to the information which we possess. Although Faraday produced "steels" with nearly 90 per cent. of platinum, and with 50 per cent. of rhodium, these very highly alloyed materials, which became separated from the remainder, have not yet with certainty been recovered. This is the more disappointing in that in these platinum alloys the first stainless steel was produced. There is some reason, however, to hope that they have now been recovered.

At a much later date, in 1857, a fourth paper of a more or less metallurgical character was published. This dealt with thin metallic films. In particular, Faraday investigated the properties of gold leaf and very nearly supplanted Beilby as the introducer of a theory of the cause of the hardening of metals by cold-working them, which is generally known as the "amorphous hypothesis." In brief, this assumes that when a metal is deformed at room temperatures it becomes, in part at any rate, essentially a fluid. The following short extract from this last paper will serve to indicate how very nearly Faraday came to holding the same view. Discussing the effect of heat upon gold leaf, he says: "As already mentioned, it might be thought that the gold leaf had run up into separate particles. If this were so, the change of colour by division is not the less remarkable, and the case would fall into those brought together under the head of gold fluids."

GENERAL MEETING, DECEMBER 1st, 1931.

Mr. B. MOUAT JONES (*President*), in the Chair.

The following were elected Ordinary Members of the Society :—

ALBERT EDMUND CLAYTON, D.Sc., Lecturer in Electrical Engineering in the College of Technology, Manchester.

ERNEST NORMAN MARCHANT, Chemist, 7 Meadow Bank, Chorlton-cum-Hardy, Manchester.

ORDINARY MEETING, DECEMBER 1st, 1931.

Mr. B. MOUAT JONES (*President*), in the Chair.

Professor H. S. Taylor read a paper on :—

" Scientific Education and Research in American Institutions."

" YOUNG PEOPLE'S MEETING," JANUARY 5th, 1932.

Mr. C. E. STROMEYER (*Vice-President*) in the Chair.

The Twelfth " Young People's Meeting " was held at 3.30 p.m., when the following short illustrated addresses were given :—

" From Coal to Prussian Blue."

By Mr. R. H. CLAYTON, B.Sc.

" Sound."

By Mr. W. H. TAYLOR, M.Sc., Ph.D.

During the afternoon the guests were entertained to tea in the Common Room.

ORDINARY MEETING, JANUARY 19th, 1932.

Mr. B. MOUAT JONES (*President*) in the Chair.

A paper on

Some Experiments on Flame Movements in Gaseous Mixtures."

by Dr. COLIN CAMPBELL, Dr. C. WHITWORTH, and Mr. A. KING, M.Sc., was read.

This paper is printed in the MEMOIRS.

GENERAL MEETING, FEBRUARY 2nd., 1932.

Mr. B. MOUAT JONES (*President*), in the Chair.

The following was elected an Ordinary Member of the Society :—

HERBERT JOHN FLEURE, Professor of Geography in the University of Manchester, 123 Lapwing Lane, Didsbury, Manchester.

ORDINARY MEETING, FEBRUARY 2nd, 1932.

Mr. B. MOUAT JONES (*President*), in the Chair.

Mr. Stromeyer suggested that whereas men, monkeys and owls have their eyes placed in the fronts of their faces, and use them for rapidly judging distances by what may be called a triangulation method, birds and animals whose eyes are placed at the sides of their heads can only use them in the same way as rangefinders are used on battleships. The shape of an object is measured point by point, as can be noticed by watching the ever-changing size of the pupil of a parrot's eye. Such surveys take time, and account for the jerky movements of the heads of birds.

Mr. D. C. Henry opened a discussion on COLOUR VISION AND COLOUR BLINDNESS, with an account of the classical three-components theory of colour vision applicable to the light-adapted eye—vision under conditions of dark adaptation is colour blind and probably due to an entirely separate mechanism. The theory was based on the facts of colour mixture. It is found that all colours can be matched in hue by an admixture of red, green and blue stimuli, and that the match can be made exact for saturation as well if the primary green stimulus is assumed to be a colour more saturated than any normally observable green. The eye is therefore supposed to contain three sets of receiving organs sensitive respectively to red, green and blue, showing sensitivity curves over the spectrum somewhat similar to resonance curves. Any colour sensation is excited by the stimulation, in varying degrees, of these three receptors. A demonstration of colour mixing with the Ives photochromoscope was given in illustration of the theory.

Mr. H. E. O. James dealt with phenomena to account for which the three-components theory requires extension. Vision on the periphery of the retina is not trichromatic but achromatic; medial regions are yellow-blue sensitive, and only at the centre of the retina is trichromatism complete. "Spatial induction"—the influence of background colour on apparent colour of a central patch—is difficult to reconcile with the simple three-components theory, as also is "successive contrast"—the influence on a colour sensation of previous stimulation of the same area of the retina. On the three-components theory, the form of colour-blindness known as dichromatism is attributed to the absence or deficiency of one of the primary receptors; on this view a dichromat should not appreciate yellow as a distinct colour, whereas experiments with subjects who are dichromatic in one eye only shows that they do in fact do this. The large variety of "anomalous trichromats" involves extensive subsidiary hypotheses if they are to be reconciled with the theory, while to the psychologist the individuality of the yellow sensation, which is never described as a reddish green, is a stumbling block to the acceptance of the three-components theory. Nevertheless the speaker considered that a satisfactory theory may eventually be developed on the three-component basis.

Mr. W. O. D. Pierce mentioned, as difficulties in the theory, the change in saturation of a colour with varying intensity, and

the existence of subjects who have normal vision of coloured lights, but abnormal vision of pigments.

Numerous members took part in the discussion which followed, and demonstrations were given of three-colour mixing and various colour blindness tests.

COUNCIL MEETING, FEBRUARY 16th, 1932.

Mr. B. MOUAT JONES (*President*), in the Chair.

Miss Doris Withington, M.Sc., and Dr. J. Wilfrid Jackson, F.G.S., were elected Hon. Auditors of the Society's accounts for the Session 1931-32.

ORDINARY MEETING, FEBRUARY 16th, 1932.

A meeting of the Society was held at the General Post Office where, by the kindness of members of the Post Office Staff, a special demonstration of the working of an automatic telephone exchange and of the Creed " Teleprinter " was given.

ORDINARY MEETING, MARCH 1st, 1932.

Mr. B. MOUAT JONES (*President*), in the Chair.

Mr. A. D. RITCHIE, M.A., read a paper on :—

" Organisms and Mechanisms : the Philosophy of the Organic Whole."

There has been much discussion on the importance of recognising that living things are organic wholes and not mere aggregates of separable parts. Too little consideration has been given to the problem of what is meant by an organism and whether any radical departure from the conceptions of physics and chemistry is involved. In physical theory, atoms, molecules and wave systems are all treated as wholes and have some claim to be considered as organisms. There are degrees of organisation among organisms, and perhaps living

things merely show to the greatest extent what is to a slight extent apparent among the non-living.

To assert that the growth and development of living organisms involves real change and origination and is not to be accounted for simply by the shuffling of pre-existing entities is not such a complete departure from physical theory as appears at first sight. The Second Law of Thermodynamics, by asserting that there are real changes and irreversible processes, has already made a break in the classical physical theory, which may prepare the way for the conceptions necessary to biology.

SPECIAL MEETING, MARCH 15th, 1932.

Mr. B. MOUAT JONES (*President*), in the Chair.

Sir ARTHUR SMITH-WOODWARD, LL.D., F.R.S., delivered the Wilde Memorial Lecture on :—

"Man's Place in Nature as shown by Fossils."

This lecture is printed in the MEMOIRS.

ANNUAL GENERAL MEETING, APRIL 19th, 1932.

Mr. B. MOUAT JONES (*President*), in the Chair.

The Annual Report of the Council and the Statement of Accounts were presented, and it was resolved :—

"That the Annual Report, together with the Statement of Accounts, be adopted, and that they be printed in the Society's PROCEEDINGS."

A vote of thanks to the Auditors was passed.

The following members were elected officers of the Society and Members of the Council for the ensuing year :—

President. B. MOUAT JONES, D.S.O., M.A.

Vice-Presidents. W. L. Bragg, O.B.E., M.A., F.R.S.; G. H. Carpenter, D.Sc.; H. Levinstein, D.Sc., M.Sc., F.I.C.; C. E. Stromeyer, O.B.E., M.Inst.C.E.

Hon. Secretaries. D. C. Henry, M.A.; W. B. Wright, Sc.D., F.G.S.

Hon. Treasurer. R. H. Clayton, B.Sc.

Hon. Librarians. C. L. Barnes, M.A.; E. C. S. Dickson, B.A., Ph.D.

Hon. Curator. J. R. Ashworth, D.Sc.

Other Members of the Council. G. N. Burkhardt, M.Sc., Ph.D.; J. D. Chorlton, M.Sc.; R. W. James, M.A., B.Sc.; P. Guthlac Jones; Arthur Lapworth, D.Sc., LL.D., F.R.S.; R. H. Pickard, D.Sc., F.R.S.; A. D. Ritchie, M.A.; A. Schedler, Ph.D.; Franklin Thorp.

ORDINARY MEETING, APRIL 19th, 1932.

Mr. B. MOUAT JONES (*President*), in the Chair.

The following papers were read :—

"The Relative Value of Coal-Measure Plants in Stratigraphy."

By R. CROOKALL, D.P.H.
(In title only.)

This paper is printed in the MEMOIRS.

"Some Chromosome numbers in British Species of *Rubus*."

By Mrs. SAROJINI DATTA.
(In title only.)

This paper is printed in the MEMOIRS.

"Electrical Phenomena caused by Light."

By F. H. CONSTABLE, D.Sc., Ph.D., F.I.C.

The earliest observations on the effect of light on electrical conductivity were described and discussed, and modern developments making use of each of the properties were described.

The effects of light on solutions and electrode potentials,

give a cell the voltage of which varies with the light intensity. The discovery of the fact that light rendered easier the passage of sparks between electrodes led to the discovery of the photo-electric effect and the photo-electric cells. A description was given of some of the more interesting types and their properties. The photo-conducting cells, their development and properties were outlined. The use of the Thalofide cell for secret signalling was described. The use of the selenium cell in street lighting, counting, race-timing and sorting was described, and the photo-cells in use for measuring work and for smoke control were discussed. The functioning and construction of the copper oxide cell was referred to as one of the later developments.

GENERAL MEETING, MAY 3rd, 1932.

Mr. B. MOUAT JONES (*President*), in the Chair.

The following was elected an Ordinary Member of the Society :—

JOHN THOMAS, M.A., D.Sc., Imperial Chemical Industries, Ltd., Blackley, Manchester.

ORDINARY MEETING, MAY 3rd, 1932.

Mr. B. MOUAT JONES (*President*), in the Chair.

Dr. H. LOWERY, M.Sc., Ph.D., read a paper on :—

"Some New Tests for use in the Estimation of Musical Capacity."

This paper is printed in the MEMOIRS.

CHEMICAL SECTION.

ORDINARY MEETING, OCTOBER 30th, 1931.

Mr. R. C. WALTHEW, M.Sc. Tech., introduced a discussion on :—

" Fuels."

A Joint Meeting of the Society with the Manchester Sections of the Society of Dyers and Colourists, the Society of Chemical Industry, and the Institute of Chemistry, was held on November 6th, 1931.

Dr. HERMANN MARK (Ludwigshafen) read a paper on :—

" The Significance of the New Cellulose Model (Molecular structure) in relation to the Technical and Dyeing properties of the Fibre."

In recent years our knowledge of the structure of cellulose, in a purely scientific sense, has advanced considerably. By a combination of chemical and X-ray data a cellulose model has been developed which agrees well with the reactions known up to the present. This model has certainly not yet been developed to its ultimate degree of perfection, and doubtless certain alterations will be made in the next few years. Nevertheless, it appears to afford an explanation of the more important technical problems. It was shown in the paper that the high absolute value of the tenacity of natural cellulose, and alterations in the plastic deformation of cellulose are explained by the model, as well as its dyeing properties and the changes produced during manufacturing processes.

ORDINARY MEETING, FRIDAY, NOVEMBER 27th, 1931.

Mr. J. M. PRESTON, B.Sc., A.I.C., introduced a discussion on :—

" Textile Microscopy in Relation to Fibre Structure."

A Combined Meeting of the Chemical Section of the Society with the Manchester Section of the Society of Dyers and Colourists, December 11th, 1931.

Mr. A. J. CROCKATT, M.Sc., A.I.C., read a paper on :—

" Garment Dyeing—An aspect of Union Dyeing."

ORDINARY MEETING, FRIDAY, JANUARY 29th, 1932.

Dr. T. K. WALKER introduced a discussion on :—

" The Trend of Recent Developments in Enzyme Chemistry."

ORDINARY MEETING, FEBRUARY 26th, 1932.

Mr. R. E. FORBESTER, M.Sc., introduced a discussion on :—

" The Chemistry and Industrial Applications of Asbestos."

ANNUAL GENERAL MEETING, MARCH 18th, 1932.

The following members were elected Officers and Members of the Committee of the Section for the year 1932-33 :—

Chairman. R. Humphries, A.I.C.

Vice-Chairman. J. T. Allpass.

Secretary. David M. Paul, B.Sc., A.I.C.

Committee. Miss A. C. Alexander, B.Sc.; L. M. Angus-Butterworth, F.R.G.S., F.S.A.; M. F. S. Choate; A. Gill, B.Sc., A.I.C.; J. R. Hannay; E. N. Marchant; T. O. Morgan; C. W. Soutar, M.A., Ph.D.; F. H. Terleski.

ORDINARY MEETING, MARCH 18th, 1932.

Mr. W. Charlton, B.Sc., Ph.D., introduced a discussion on :—

"Electronic Theories in Organic Chemistry."

ANNUAL REPORT OF THE COUNCIL, APRIL, 1932

Membership.

During the session thirteen new members have been elected. Two ordinary members (Mr. A. Adamson and Mr. E. B. Wardleworth) and two honorary members (Mr. T. A. Edison and Mr. C. P. Scott) have died.

To March 31st, 1932, there were 217 ordinary members of the Society, including five life members.

Student Associates.

Under the regulations governing the admission of "Student Associates" which came into force at the beginning of the session 1921-22, the Council admitted three such members.

Meetings.

Thirteen papers have been read at the Society's ordinary meetings during the year, April 1st, 1931, to March 31st, 1932. At the first meeting of the session members of the Society spoke on points of scientific interest discussed before the British Association meetings, and on February 2nd, 1932, there was a discussion on Colour Blindness. A special demonstration to the Society of the working of an automatic telephone exchange and of the Creed "Teleprinter" was given at the General Post Office.

Six meetings and a Soirée have been held by the Chemical Section.

The "Young People's Meeting" was held on January 5th, 1932, when addresses were given by Mr. R. H. Clayton, B.Sc., and Mr. W. H. Taylor, M.Sc., Ph.D.

A joint meeting with other Manchester scientific societies was held on November 6th in the College of Technology, when Dr. Hermann Mark lectured on "The Significance of the New Cellulose Model for the Technical and Dyeing Properties of the Fibre."

A joint meeting of the Chemical Section with the Society of Dyers and Colourists was held on December 11th in the

Society's rooms, at which a paper on "Garment Dyeing—An Aspect of Union Dyeing" was read by Mr. A. J. Crockatt, M.Sc.

The Society co-operated with certain Manchester scientific societies in holding a Conversazione in the University on September 21st, 1931, in connection with the Faraday Celebrations.

Society's Accounts.

The cash account of the Society is appended to this report, together with a statement of assets and liabilities.

Society's Library.

The total number of volumes catalogued to date is approximately 45,415.

The additions to the Library during the session amount to 830 volumes, 821 serials, and 9 separate works. 341 volumes have been bound, and gifts of books have been received from Mr. Stromeyer, Mr. Gaunt, Professor Wild and others.

315 volumes have been borrowed from the Library.

During the session volume 75 (1930-31) of the *Memoirs and Proceedings* has been published.

New exchanges have been arranged with the following :—

Auckland Institute and Museum.
The Belfast Naturalists' Field Club.
Revista Matematica Hispano-Americana.
Musée Royal d'Histoire Naturelle de Belgique.

Donations.

A photograph of the total eclipse of the sun, taken at Giggleswick.—Presented by Mr. Stromeyer.

Two engravings : one of John Dalton and one of Sir Humphry Davy.—Presented by Mr. J. Kirkby.

Photographs of John Dalton's birthplace.—Presented by Mr. W. Humphreys.

Chemical Section.

At the Annual General Meeting of the Section, the following officers were elected :—

Chairman : Mr. R. Humphries, A.I.C. ; *Vice-Chairman :* Mr. J. T. Allpass ; *Secretary :* Mr. David M. Paul.

The Section had a membership of 82 at the end of the session.

The following subjects were discussed at the meetings held during the year :—

"Fuels" (Mr. R. C. Walthew, M.Sc., A.I.C.); "Textile Microscopy in Relation to Fibre Structure" (Mr. J. M. Preston, B.Sc., A.I.C.); "The Trend of Recent Developments in Enzyme Chemistry" (Dr. T. K. Walker); "The Chemistry and Industrial Applications of Asbestos" (Mr. R. E. Forbester, M.Sc.); "Electronic Theories in Organic Chemistry" (Mr. W. Charlton, B.Sc., Ph.D.).

Visiting Societies.

The following Societies have held their meetings in the Society's rooms: The Manchester Astronomical Society; The Institution of Civil Engineers (Manchester Association); The Manchester Microscopical Society; The Manchester Statistical Society; The Society of Dyers and Colourists (Manchester Section); and the Institution of Locomotive Engineers (Manchester Centre).

Committees.

The Committees appointed by the Council during the year were as follows :—

House and Finance:

Dr. Carpenter and Mr. Thorp.

Wilde Endowment:

Dr. Carpenter and Dr. Pickard.

Publications:

Mr. R. W. James, Professor Lapworth, Mr. Scholefield, and Mr. Ritchie.

Library and Apparatus:

Dr. Carpenter, Professor Bragg, and Dr. Pickard.

New Premises:

Mr. R. W. James, Dr. Levinstein, and Mr. Thorp.

The President, the Honorary Secretaries, the Honorary Treasurer and the Honorary Librarians are *ex-officio* members of the above committees.

Chemical Section:

Mr. Allpass, Miss Alexander, Mr. Angus-Butterworth, Mr. Cheetham, Mr. Choate, Mr. Gill, Mr. Horner, Mr. Humphries, Mr. Paul, Mr. Silvester, Dr. Soutar and Mr. Terleski.

MANCHESTER LITERARY

Dr. *R. H. Clayton, Treasurer, in Account with the*

GENERAL

			£	s.	d.	£	s.	d.
To Balance in Treasurer's Hands, 1st April, 1931						5	10	5
To Members' Subscriptions :—								
Half Rate	1930-31,	5 at £1 1s. od.	5	5	0			
,,	1931-32,	12 ,, ,,	12	12	0			
Full Rate	1928-29,	2 ,, £2 2s. od.	4	4	0			
,,	1929-30,	8 ,, ,,	16	16	0			
,,	1930-31,	32 ,, ,,	67	4	0			
,,	1931-32,	146 ,, ,,	306	12	0			
Half Year	1931-32,	1 ,, £1 1s. od.	1	1	0			
Student Associates	1930-31,	2 ,, 5s. od.		10	0			
	1931-32,	2 ,, ,,		10	0			
						414	14	0
To Sale of Publications						25	19	6
To Dividends :—								
Natural History Fund			45	18	9			
Joule Memorial Fund			13	4	1			
General Fund			3	15	0			
						62	17	10
To Transfer from Wilde Endowment Fund .						29	8	0
To Receipts from Visiting Societies for Expenses of Meetings :—Institution of Civil Engineers (Manchester Association)			27	10	0			
Manchester Astronomical Society . . .			8	0	0			
,, Statistical Society			6	0	0			
,, Microscopical Society . . .			25	0	0			
,, Inst. of Locomotive Engineers .			12	12	0			
Society of Dyers and Colourists (Manchester Section)			5	0	0			
						84	2	0
To Returned Income Tax						112	5	2
To Postage Expenses Refunded						1	3	9
To Refund on Insurance Premiums . . .						2	5	0
To Overdraft at Bank						492	4	4
						£1230	10	0

AND PHILOSOPHICAL SOCIETY.

Society, from 1st April, 1931, to 31st March, 1932. **Cr.**

FUND.

	£	s.	d.	£	s.	d.
By Overdraft at Bank, 1st April, 1931 . .				458	1	3
By Charges on Property :—						
Chief Rent	9	13	8			
Insurance against Fire	15	0	0			
Income Tax	3	4	6			
				27	18	2
By House Expenditure :—						
Coal, Gas, Electric Light, Water, etc. . .	63	17	7			
Tea, Coffee, etc., at Meetings	9	10	11			
Cleaning, etc.	7	16	6½			
Replacements	8	18	11			
Repairs, etc.	24	5	2			
				114	9	1½
By Administrative Charges :—						
Caretaker and Housekeeper	126	15	0			
Extra attendance at Meetings	2	5	0			
Insurance against Liability		15	9			
Postages, Carriage of Parcels	30	10	2			
Stationery, &c.	14	18	0			
Bank Charges	4	5	7			
Share of Expenses of Joint Meeting . .	1	2	9			
Sesquicentenary and Faraday Celebrations Expenses	38	9	3			
National Health Insurance Stamps . .	9	11	0			
Young People's Meeting Expenses . .	9	13	7			
Miscellaneous Expenses	13	8	6			
				251	14	7
By Printing "Memoirs and Proceedings," Circulars, etc. .				215	10	6
By Periodicals (except those charged to Natural History Fund)				86	7	0
By Post Office Telephone				11	7	3
By Natural History Fund :— (Items shown in Balance Sheet of this Fund) . .				28	1	3
By Restoring Society's Pictures				2	10	0
By Extra Assistance in Library				5	0	0
By Cash in Treasurer's Hands				29	10	10½
				£1230	10	0

WILDE ENDOWMENT FUND, 1931-32.

Dr.	£	s.	d.	Cr.		£	s.	d.
To Balance at Bank, 1st April, 1931	588	6	4	By Assistant Secretary's Salary		162	10	0
To Dividend on £7500 Gas Light and Coke Company's Ordinary Stock	320	5	0	By Bookbinding		76	17	3
To Interest on £50 5 per cent. War Loan Stock	1	17	6	By Honorarium to Assistant Secretary		10	0	0
To Bank Interest	4	6	10	By Wilde Memorial Lecture		15	4	0
				By Transferred to General Fund—				
				16 Subscriptions at £1 1s. 0d.	£16 16 0			
				Entrance Fees	12 12 0			
						29	8	0
				By Bank charges			4	2
				By Balance at 1st April, 1932		620	12	3
	£914	15	8			£914	15	8

BUILDING FUND, 1931-32.

Dr.	£	s.	d.	Cr.	£	s.	d.
To Balance at Bank, 1st April, 1932	238	5	2	By Repairs to Back George Street Property	54	12	2
To Rents	41	8	5	By Balance at 1st April, 1932	246	13	5
To Interest on £500 4 per cent. Funding Loan	20	0	0				
To Bank Interest	1	12	0				
	£301	5	7		£301	5	7

JOULE MEMORIAL FUND, 1931-32. (Included in the General Account, above.)

Dr.	£	s.	d.	Cr.	£	s.	d.
To Dividend on £100 East India Railway Company's 4½ per cent. Annuity Class A Stock	3	16	7	By Balance Transferred to the General Fund	13	4	1
To Interest on £250 5 per cent. War Loan Stock	9	7	6				
	£13	4	1		£13	4	1

NATURAL HISTORY FUND, 1931-32. (Included in the General Account, above.)

Dr.	£	s.	d.	Cr.	£	s.	d.
To Dividend on £1225 Great Western Railway Company's Stock	45	18	9	By Natural History Periodicals	18	5	3
				By Subscriptions :—			
				Entomological Society, 1931 and 1932	4	4	0
				North Western Naturalists' Union, 1930 and 1931	1	8	0
				Palæontographical Society, 1929, 1930, 1931	3	3	0
				Ray Society, 1932	1	1	0
				By Balance Transferred to General Fund	17	17	6
	£45	18	9		£45	18	9

STATEMENT RELATING TO THE SOCIETY'S PROPERTY AS ON 31st MARCH, 1932.

LIABILITIES.	£	s.	d.	ASSETS.	£	s.	d.
Printing :—				Arrears of Subscriptions, 1931-32 (estimated to produce)	73	10	0
In the Press. Vol. 76 (approximately)	150	0	0	Arrears of Subscriptions, earlier (estimated to produce)	50	8	0
Binding	75	0	0	Income Tax (recoverable) April 1st, 1931—March 31st, 1932	110	0	0
Restoration of Pictures	10	0	0	Rents to Lady Day, 1932	15	10	0
Overdraft at Bank (General Fund)	492	4	4	Expenses of Meetings	14	0	0
				Cash Balance :—			
				In Bank, Building Fund	246	13	5
				,, Wilde Endowment Fund	620	12	3
	£727	4	4		£1130	13	8
				Investments :—			
				£7500 Gas Light and Coke Company's Ordinary Stock (W.E.F.)			
				£1225 Great Western Railway Company's 5 per cent. Consolidated Preference Stock (Nat. Hist. F.)			
				£100 East India Railway Company's 4½ per cent. Annuity Class A (J.M.F.)			
				£250 5 per cent. War Loan Stock, 1929-47 (J.M.F.)			
				£50 ,, ,, ,, ,, (W.E.F.)			
				£75 ,, ,, ,, ,, (Gen. Fund)			
				£500 4 per cent. Funding Loan (Building Fund)			
There are 5 Life Composition Fees.				Society's Premises, Furniture, Library, Collections, Stock of Unsold Publications, and New Premises, 21 and 21A Back George Street.			

NOTE.—The Treasurer's Accounts of the Session 1931-32 have been endorsed as follows:—

April 11th, 1932. Audited and found correct.

We have seen at this date the Bankers' certificate that they hold £375 of 5 per cent. War Loan Bonds:—2 Bonds for £100 each, Nos. 71,827 and 366,270; 2 Bonds for £50 each, Nos. 131,577 and 31,358; 1 Bond for £50, and a Bond for £25, 5 per cent. War Loan, 1929/47 Inscribed Stock; and the Certificates of the following Stocks:—£1225 Great Western Railway Company 5 per cent. Consolidated Preference Stock, Nos. 12,293, 12,294, and 12,323; £7500 Gas Light and Coke Company Ordinary Stock (No. 8/1960); £100 East India Railway Company £4 10s. per cent. Annuity Class A Stock (No. 25,656) and the deeds of the Natural History Fund, of the Wilde Endowment Fund, those conveying the land on which the Society's premises stand, and the Declarations of Trust.

Leases and Conveyances dated as follows:—

22nd Sept., 1797.
23rd Sept., 1797.
25th Dec., 1799.
25th Dec., 1799.
22nd Dec., 1820.
23rd Dec., 1820.

Declarations of Trust:—

24th June, 1801.
23rd Dec., 1820.
8th Jan., 1878.

Appointment of New Trustees:—

30th April, 1851.

Conveyance, relating to the property, 21 Back George Street, Manchester, dated 7th December, 1920.

We have also seen the Dalton medals, etc.

We have verified the balances of the various accounts with the bankers' pass books.

(*Signed*) J. WILFRID JACKSON.
DORIS WITHINGTON.

LIST OF SOCIETIES AND INSTITUTIONS.

TO WHICH THE *Memoirs and Proceedings* ARE SENT.

Societies and Institutions present their publications to the Society's Library with the exception of those marked with a dagger (†).

Aberystwyth. †National Library of Wales. †Subject Index to Periodicals.

Abo. Akademie Bibliotek.

Adelaide. Royal Society of Australia. South Australian Museum.

Amsterdam. Koninklijke Akademie van Wetenschappen. Société Mathématique.

Augsburg. Der naturwissenschaftlicher Verein für Schwaben.

Auckland. The Auckland Institute and Museum.

Baltimore. Johns Hopkins University.

Bamberg. Naturforschende Gesellschaft.

Bangalore (Madras). Indian Institute of Science.

Basel. Naturforschende Gesellschaft. Helvetica Chimica Acta.

Batavia. Koninklijke Natuurkundige Vereeniging in Nederlandsch-Indië. Bataviaasch Genootschap van Kunsten en Wetenschappen.

Bath. Bath and West and South Counties Society.

Belfast. Naturalists' Field Club.

Bergen. Geofysisk Institutt.

Berkeley. University of California.

Berlin. Preussische Akademie der Wissenschaften.

Berne. Schweizerische Naturforschende Gesellschaft.

Besançon. Société d'émulation de Doubs.

Birmingham. Natural History and Philosophical Society.

Bloemfontein. National Museum.

Bologna. Reale Accademia delle Scienze dell'Istituto.

Bombay. Branch of the Royal Asiatic Society of Bengal.

Bonn. Naturhistorischer Verein der preussischen Rheinlande und Westfalens.

Bordeaux. Société des Sciences physiques et naturelles.

Boston. American Academy of Arts and Sciences. Society of Natural History.

Boulder. University of Colorado.

Bremen. Naturwissenschaftlichen Verein.

Brisbane. Queensland Museum. Royal Society of Queensland. Royal Geographical Society of Australia, Queensland Branch.

Bristol. Naturalists' Society.

Brno. Faculty of Science, Masaryk University.

Brooklyn (N. Y.). Institute of Arts and Sciences.

Brussels. Académie Royale de Belgique. Musée Royal d'Histoire Naturelle de Belgique.

Buenos Aires. Sociedad Cientifica Argentina.

Buffalo. Society of Natural Sciences.

Caen. Académie nationale des Sciences, Arts et Belles-Lettres. †Société Linnéenne de Normandie.

Calcutta. Department of Agriculture in India, Agricultural Research Institute (Pusa). Geological Survey of India. Indian Association for the Cultivation of Science. Meteorological Department of India (Poona). Royal Asiatic Society of Bengal.

Cambridge. Philosophical Society. †University Library.

Cambridge (Mass.) Harvard College. †Massachusetts Institute of Technology Library.

Cape Town. Royal Society of South Africa. South African Museum.

Cardiff. Naturalists' Society.

Catania. Accademia Gioenia di Scienze naturali.

Chambéry. Académie des Sciences, Belles-Lettres et Arts de Savoie.

Chapel Hill. Elisha Mitchell Scientific Society.

Charlottenburg. Physikalisches-Technischen Reichsanstalt.

Cherbourg. Société nationale des Sciences naturelles.

Chicago. Astrophysical Journal. Field Museum of Natural History.

Cincinnati. Lloyd Library and Museum. †American Association for the Advancement of Science. Society of Natural History.

Clermont-Ferrand. La Société des amis de l'Université de Clermont.

Colorado Springs. Colorado College Coburn Library.

Columbia. University of Missouri.

Columbus. Ohio State University.

Copenhagen. Kongeligt Danske Videnskabernes Selskab. Kongeligt Nordisk Oldskrift-Selskab. Naturhistorisk Förening.

Cracow. Société Polonaise Mathématique.

Cullercoats. See Newcastle-upon-Tyne.

Danzig. Naturforschende Gesellschaft. Westpreussischer Botanisch-Zoologischer Verein.
Davenport. Academy of Natural Sciences.
Delft. Technische Hoogeschool.
Des Moines. Iowa Geological Survey.
Dijon. Académie des Sciences, Arts et Belles-Lettres.
Dorpat. Naturforschende Gesellschaft.
Douai. Société d'Agriculture, Sciences et Arts du Départment du Nord.
Draguignan. Société d'études Scientifiques et Archéologiques.
Dublin. †National Library of Ireland. Royal Dublin Society. Royal Irish Academy. †Trinity College Library.
Dunkerque. Société Dunkerquoise pour l'encouragement des Sciences.
Durban. †Corporation Museum.

Elberfeld. Naturwissenschaftlicher Verein.
Épinal. Société d'émulation des départmentes des Vosges.
Edinburgh. Botanical Society. Geological Society. Mathematical Society. †National Library of Scotland. Royal Botanic Gardens. Royal Observatory. Royal Physical Society. Royal Society. Royal Scottish Society of Arts. †Scottish Meteorological Society.
Erlangen. Physikalisch-medizinische Societät.
Evreux. Société libre d'Agriculture, Sciences, Arts et Belles-Lettres de l'Eure.

Falmouth. Royal Cornwall Polytechnic Society.
Florence (Firenze). Biblioteca Nazionale Centrale.
Frankfurt-am-Main. Physikalischer Verein. Senckenbergische Naturforschende Gesellschaft.
Freiburg i. Br. Naturforschende Gesellschaft.

Geneva. Institute national Génévois. Société de Physique et d'Histoire Naturelle. See also Basel.
Genova. Museo Civico di Storia Naturale.
Giessen. Oberhessische Gesellschaft für Natur-und Heilkunde.
Glasgow. Geological Society. Natural History and Microscopical Society. Royal Philosophical Society. †University Library.
Görlitz. Naturforschende Gesellschaft.
Göteborg. Göteborgs Stadtsbibliotech (Högskole).
Göttingen. Gesellschaft der Wissenschaften.
Grahamstown. Albany Museum.

Granville. Denison University.
Gratz. Verein des Aertze in Steiermark.
Greenwich. Royal Observatory.

Haarlem. Hollandsche Maatschappig der Wetenschappen. Musée Teyler. Nederlandsche Maatschappig ter bevordering van Nijverheid.
Halifax, N.S. Nova Scotian Institute of Science.
Halle. Kaiserliche Akademie der Naturforscher. Naturforschende Gesellschaft und Naturwissenschaftlicher Verein.
Hamburg. Naturwissenschaftlicher Verein.
Hanley. See Stoke-on-Trent.
Hannover. Naturhistorische Gesellschaft.
Hartford (Conn.). Connecticut State Library (Geological and Natural History Survey).
Heerlen. Geologisch Bureau van het Nederlandsch Mijngebied.
Heidelberg. Bädische Sternwarte. Naturhistorisch-medizinischer Verein.
Helsingfors. Finska Vetenskaps Societeten. Societas pro Fauna et Flora Fennica.
Hermannstadt. Siebenbürgischer Verein für Naturwissenschaften.
Hobart. Royal Society of Tasmania.
Hong Kong. Royal Observatory.
Hull. †Scientific and Field Naturalists' Club. †Yorkshire Naturalists' Union.

Indianapolis. Department of Geology and Natural Resources of Indiana.
Iowa City. Iowa State University.
Ithaca. Cornell University. Agricultural Experimental Station.

Johannesburg. South African Association for the Advancement of Science.

Kazan. Imperial University. Society of Archæology.
Kiel. Kommission zur wissenschaftlicher Untersuchung der deutschen Meere in Kiel. Naturwissenschaftlicher Verein für Schleswig-Holstein.
Kiev. Society of Naturalists.
Kodaikanal. See Madras.
Königsberg i. Pr. Königliche Universitäts-Sternwarte. Königliche Physikalisch-ökonomisch Gesellschaft.
Kyoto. College of Science and Engineering, Imperial University.

La Plata. Direccion General de Estadistica de la Prov. Buenos Aires. Universidad Nacional, Facultad de Ciencias Fisico-Matematicas.

Lausanne. Société Vaudois des Sciences Naturelles.

Lawrence. Kansas University.

Leeds. Philosophical and Literary Society. Yorkshire Geological Society. Leeds Geological Association.

Leeuwarden. Friesch Genootschap, van Geschied-, Oudheid -en Taalkunde.

Leicester. Literary and Philosophical Society.

Leiden. Maatschappig der Nederlandsch Letterkunde. Rijks Geologisch—Mineralogisch Museum. Rijks Herbarium.

Leipzig. Naturforschende Gesellschaft. Fürstliche Jablonowskische Gesellschaft. Sächsische Gesellschaft der Wissenschaften.

Le Mans. Société d'Agriculture, Sciences et Arts de la Sarthe.

Lemberg. Société Scientifique de Chevtchenko.

Leningrad. Academy of Sciences of the Union of Socialist Soviet Republics.

Liége. Société Géologique de Belgique. Société Royal des Sciences.

Lille. Société des Sciences de l'Agriculture et des Arts. L'Université.

Lima, Peru. Cuerpo de Inginieros de Minas del Peru.

Lincoln, U.S.A. University of Nebraska.

Liverpool. Biological Society. Engineering Society. Geological Society. Literary and Philosophical Society.

London. British Association. British Museum (Natural History). Chemical Society. Faraday Society. Geological Society. Institution of Civil Engineers. Institution of Electrical Engineers. Institution of Mechanical Engineers. Linnean Society. Mathematical Society. Meteorological Office. Optical Society. Patent Office. Physical Society. Quekett Microscopical Society. Royal Society. Royal Astronomical Society. Royal Geographical Society. Royal Horticultural Society. Royal Institute of British Architects. Royal Institution of Great Britain. Royal Meteorological Society. Royal Society of Arts. Zoological Society.

Lucca. Reale Accademia Lucchese di Scienze, Lettere, ed Arti.

Lund. Universitet.

Luxembourg. Institute Grand Ducal de Luxembourg.

Lwow. See Lemberg.

Lyon. Académie des Sciences, L'Université.

Madison. Wisconsin Academy of Sciences, Arts and Letters. Wisconsin Geological and Natural History Survey.

Madras. Observatory (Kodaikanal).

Madrid. Real Academia de Ciencias. Real Sociedad Matemática Española.

Manchester. Association of Engineers. †Athenæum. †Chetham's Library. †Christie Library. Conchological Society. Geographical Society. Geological Association. Microscopical Society. †Municipal College of Technology. †Reference Library. Shirley Institute. Statistical Society. Textile Institute.

Manila. Bureau of Ethnology. Bureau of Science.

Marburg. Gesellschaft zur Beförderung der gesammten Naturwissenschaften.

Marseille. Faculté des Sciences de l'Université.

Melbourne. Royal Society of Victoria.

Metz. Académie de Metz.

Mexico. Instituto Geológico. Sociedad Cientifico "Antonio Alzate."

Middleburg. Zeeuwsch Genootschap der Wetenschappen.

Milan. Reale Istituto Lombardo di Scienze e Lettere. Reale Osservatorio di Brera in Milano (Merati, Como.). Società Italiana di Scienze Naturali, e Museo Civico.

Minneapolis. University of Minnesota. †Academy of Natural Sciences.

Missoula. University of Montana.

Modena. Regia Accademia di Scienze, Lettere ed Arti.

Monte Video. Museo de Historia Natural.

Montpellier. Académie des Sciences et Lettres.

Montreal. Royal Society of Canada.

Munich. Bayerische Akademie der Wissenschaft.

Nancy. Société des Sciences de Nancy.

Naples. Accademia delle Scienze fisiche e matematiche. Accademia di Archeologia, Lettere e Belle Arti. Società Reale di Scienze.

Neuchâtel. Société neuchâteloise des Sciences naturelles.

Newcastle-upon-Tyne. Dove Marine Laboratories, Cullercoats. †Literary and Philosophical Society. Natural History Society of Northumberland, Durham, and Newcastle-upon-Tyne. University of Durham Philosophical Society.

New Haven (Conn.). Connecticut Academy of Arts and Sciences. Bingham Oceanographic Collection.

New York. Academy of Sciences. American Chemical Society. American Mathematical Society. American Museum of Natural History. Meteorological Observatory (Central Park). Vanderbilt Marine Museum.

Nîmes. Académie de Nîmes.

Norman. Oklahoma Academy of Science.

Norwich. Norfolk and Norwich Naturalists' Society.

Offenbach. Der Offenbacher Verein für Naturkunde.

Oslo. Norske Videnskaps Akademie. Norsk Meteorologisk Institut. Observatorium. Bibliothèque de l'Université Royale de Norvège.

Ottawa. Geological Survey of Canada.

Oxford. †Bodleian Library. Radcliffe Observatory. Radcliffe Library.

Palermo. Reale Accademia di Scienze, Lettere, e Belle Arti.

Paris. Académie des Sciences. École nationale supérieur des Mines. École polytechnique. Muséum d'Histoire naturelle.

Philadelphia. Academy of Natural Sciences. American Philosophical Society. Franklin Institute. †Philadelphia Commercial Museum. Wagner Free Institute of Science.

Pietermaritzburg. †Government Geologist, Surveyor General's Office. Natal Government Museum.

Plymouth. Plymouth Institution and Devon and Cornwall Natural History Society.

Portici. Laboratorio di Zoologia generale e agraria, R. Scuola sup. di Agricoltura.

Porto. Academica Polytechnica.

Prague. Königliche Böhmische Gesellschaft der Wissenschaft.

Puget Sound. See Seattle.

Pusa. See Calcutta.

Rheims. Académie nationale.

Riga. Naturforscher Verein.

Rochelle. Société des Sciences naturelles de la Charente inférieure.

Rochdale. Literary and Scientific Society.

Rochester, N.Y. Academy of Science.

Rock Island. Augustana College Library.

Rome. Institut International d'Agriculture. Reale Accademia dei Lincei. Società Italiana per il progresso delle Scienze. Vatican Observatory (Specola Vaticana).

Rostock. Verein der Freunde der Naturgeschichte in Mecklenburg.
Rouen. Académie des Sciences.

Sacramento. See Berkeley.
St. Louis. Missouri Botanical Garden. †Academy of Science. The Washington University.
St. Paul. See Minneapolis.
Salford. †Royal Museum and Library.
San Diego. Society of Natural History.
San Francisco. California Academy of Sciences.
San José. See Berkeley.
Santiago. Deutscher Wissenschaftlicher Verein.
Sassari. Regia Università Istituto Fisiologico.
Seattle. University of Washington. Puget Sound Marine Biological Station.
Sendai. Tohoku Imperial University.
Sheffield. Literary and Philosophical Society. Midland Institute of Mining, Civil and Mechanical Engineers. Safety in Mines Research Board Laboratories.
Simla. See Calcutta.
Southport. Fernley Observatory.
Stockholm. Entomologiska Föreningen. Kongeliga Svenska Vetenskaps-Akademi. Royal Library. Sveriges Geologiska Undersökning.
Stoke-upon-Trent. North Staffordshire Field Club.
Stratford. The Essex Field Club.
Swansea. Scientific and Field Naturalists' Society.
Sydney. Australian Association for Science. Australian Museum. Linnean Society of New South Wales. Royal Society of New South Wales.

Tachkent. L'Université de l'Asie Centrale.
Taihoku. Imperial University.
Tartus. See Dorpat.
Teddington. National Physical Laboratory.
Tiflis. Geophysikalisches Observatorium Georgiens.
Tokyo. Faculty of Science, Imperial University of Tokyo. Imperial Academy. Institute of Electrical Engineers of Japan. National Research Council of Japan. Physico-Mathematical Society of Japan.
Torino. Società Meteorologica Italiana.
Toronto. Canadian Institute. University Library.

Toulouse. Académie des Sciences, Inscriptions, et Belles-Lettres.
Trondhjem. Kongelige Norske Videnskabers Selskab Museet.
Troyes. Société Académique d'Agriculture de l'Aube.
Tufts. Tufts College.
Turin. See Torino.

Uccle. L'Observatoire royal et l'Institut royal Météorologique de Belgique.
Upsala. Kongliga Universitet. Kongliga Vetenskaps-Societeten.
Urbana. Illinois State Geological Survey. Illinois State Laboratory of Natural History. University of Illinois.
Utrecht. Koninklijk Nederlandsch Meteorologisch Instituut. Provincial Utrechtsch Genootschap van Kunsten en Wetenschappen.

Venice. Reale Istituto Veneto di Scienze, Lettere, ed Arti.
Victoria, B.C. Dominion Astrophysical Observatory.
Vienna. Kaiserliche Akademie der Wissenschaften. Kaiserlich-Königliche Universitäts-Sternwarte. Kaiserlich-Königliches Naturhistorisches Hofmuseum. Kaiserlich-Königliche Zoologisch-Botanische Gesellschaft. Oesterreichische Gesellschaft für Meteorologie.

Washington University. See St. Louis, Mo.
Washington, University of. See Seattle.
Washington, D.C. Bureau of Standards, Dept. of Commerce and Labor. Carnegie Institute. National Academy of Sciences of the U.S.A. Smithsonian Institution. Smithsonian Institution, Bureau of Ethnology. Smithsonian Institution, United States National Museum. U.S. Coast and Geodetic Survey. U.S. Department of Agriculture. U.S. Geological Survey. U.S. Naval Observatory. †U.S. Patent Office.
Watford. Hertfordshire Natural History Society and Field Club.
Wellington, N.Z. New Zealand Institute.
Wiesbaden. Nassauischer Verein für Naturkunde.
Wurzburg. Physikalisch-medizinische Gesellschaft.

York. Yorkshire Philosophical Society.

Zurich. Naturforschende Gesellschaft. Schweizerische Meteorologische Central-Anstalt.

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THE WILDE LECTURES.

1897. (July 2.) "On the Nature of the Röntgen Rays." By Sir G. G. STOKES, Bart., F.R.S.

1898. (Mar. 29.) "On the Physical Basis of Psychical Events." By Sir MICHAEL FOSTER, K.C.B., F.R.S.

1899. (Mar. 28.) "The newly discovered Elements; and their relation to the Kinetic Theory of Gases." By Professor WILLIAM RAMSAY, F.R.S.

1900. (Feb. 13.) "The Mechanical Principles of Flight." By the Rt. HON. LORD RAYLEIGH, F.R.S.

1901. (April 22.) "Sur la Flore du Corps Humain." By Dr. ELIE METCHNIKOFF, For. Mem.R.S.

1902. (Feb. 25.) "On the Evolution of the Mental Faculties in relation to some Fundamental Principles of Motion." By Dr. HENRY WILDE, F.R.S.

1903. (May 19.) "The Atomic Theory." By Professor F. W. CLARKE, D.Sc.

1904. (Feb. 23.) "The Evolution of Matter as revealed by the Radio-active Elements." By FREDERICK SODDY, M.A.

1905. (Feb. 28.) "The Early History of Seed-bearing Plants, as recorded in the Carboniferous Flora." Dr. D. H. SCOTT, F.R.S.

1906. (March 20.) "Total Solar Eclipses." By Professor H. H. TURNER, D.Sc., F.R.S.

1907. (Feb. 18.) "The Structure of Metals." By Dr. J. A. EWING, F.R.S., M.Inst.C.E.

1908. (March 3.) "On the Physical Aspect of the Atomic Theory." By Professor J. LARMOR, Sec.R.S.

1909. (March 9.) "On the Influence of Moisture on Chemical Change in Gases." By Dr. H. BRERETON BAKER, F.R.S.

1910. (March 22.) "Recent Contributions to Theories regarding the Internal Structure of the Earth." By Sir THOMAS H. HOLLAND, K.C.I.E., D.Sc., F.R.S.

SPECIAL LECTURES.

1913. (March 4.) "The Plant and the Soil." By. A. D. HALL, M.A., F.R.S.
1914. (March 18.) "Crystalline Structure as revealed by X-rays." By Professor W. H. BRAGG, M.A., F.R.S.
1915. (May 4.) "The Place of Science in History." By Professor JULIUS MACLEOD, D.Sc.

DALTON LECTURE.

1931. (Mar. 17.) "Atoms and Electrons." By Sir Joseph J. Thomson, O.M., D.Sc., F.R.S.

JOULE MEMORIAL LECTURES.

1920. (Dec. 14.) "The Work and Discoveries of Joule." By Sir DUGALD CLERK, K.B.E., D.Sc., F.R.S.
1922. (Dec. 5.) "The Rise in Motive Power and the Work of Joule." By Sir CHARLES A. PARSONS, K.C.B., M.A., D.Sc., F.R.S.
1924. (Mar. 4.) "Thermodynamics in Physiology." By A. V. HILL, O.B.E., M.A., Sc.D., F.R.S.
1928. (Mar. 20.) "Sub-Atomic Energy." By Professor A. S. EDDINGTON, M.A., D.Sc., LL.D., F.R.S.
1930. (Feb. 18.) "Science and Problems of the Times." By A. P. M. FLEMING, C.B.E., M.Sc., M.I.E.E.

WILDE MEMORIAL LECTURES.

1926. (Mar. 9.) "Brains of Apes and Men." By G. ELLIOT SMITH, M.A., M.D., F.R.S.
1927. (Mar. 22.) "Physiology of Life in the High Andes." By J. BARCROFT, C.B.E., F.R.S.
1929. (Mar. 19.) "The Nature and Origin of Human Speech." By Sir RICHARD PAGET, Bart.
1932. (Mar. 15.) "Man's Place in Nature as shown by Fossils." By Sir ARTHUR SMITH-WOODWARD, LL.D., F.R.S.

Awards of the Dalton Medal.

1898. EDWARD SCHUNCK, Ph.D., F.R.S.
1900. Sir HENRY E. ROSCOE, F.R.S.
1903. Prof. OSBORNE REYNOLDS, LL.D., F.R.S.
1919. PROF. Sir ERNEST RUTHERFORD, M.A., D.Sc. F.R.S.
1931. Sir JOSEPH J. THOMSON, O.M., D.Sc., F.R.S.

LIST OF PRESIDENTS OF THE SOCIETY.

Date of Election.	
1781.	PETER MAINWARING, M.D., JAMES MASSEY.
1782-1786.	JAMES MASSEY, THOMAS PERCIVAL, M.D., F.R.S.
1787-1789.	JAMES MASSEY.
1789-1804.	THOMAS PERCIVAL, M.D., F.R.S.
1805-1806.	Rev. GEORGE WALKER, F.R.S.
1807-1809.	THOMAS HENRY, F.R.S.
1809.	*JOHN HULL, M.D., F.L.S.
1809-1816.	THOMAS HENRY, F.R.S.
1816-1844.	JOHN DALTON, D.C.L., F.R.S.
1844-1847.	EDWARD HOLME, M.D., F.L.S.
1848-1850.	EATON HODGKINSON, F.R.S., F.G.S.
1851-1854.	JOHN MOORE, F.L.S.
1855-1859.	Sir WILLIAM FAIRBAIRN, Bart, LL.D., F.R.S.
1860-1861.	JAMES PRESCOTT JOULE, D.C.L., F.R.S.
1862-1863.	EDWARD WILLIAM BINNEY, F.R.S., F.G.S.
1864-1865.	ROBERT ANGUS SMITH, Ph.D., F.R.S.
1866-1867.	EDWARD SCHUNCK, Ph.D., F.R.S.
1868-1869.	JAMES PRESCOTT JOULE, D.C.L., F.R.S.
1870-1871.	EDWARD WILLIAM BINNEY, F.R.S., F.G.S.
1872-1873.	JAMES PRESCOTT JOULE, D.C.L., F.R.S.
1874-1875.	EDWARD SCHUNCK, Ph.D., F.R.S.
1876-1877.	EDWARD WILLIAM BINNEY, F.R.S., F.G.S.
1878-1879.	JAMES PRESCOTT JOULE, D.C.L., F.R.S.
1880-1881.	EDWARD WILLIAM BINNEY, F.R.S., F.G.S.
1882-1883.	Sir HENRY ENFIELD ROSCOE, D.C.L., F.R.S.
1884-1885.	WILLIAM CRAWFORD WILLIAMSON, LL.D., F.R.S.
1886.	ROBERT DUKINFIELD DARBISHIRE, B.A., F.G.S.
1887.	BALFOUR STEWART, LL.D., F.R.S.
1888-1889.	OSBORNE REYNOLDS, LL.D., F.R.S.
1890-1891.	EDWARD SCHUNCK, Ph.D., F.R.S.
1892-1893.	ARTHUR SCHUSTER, Ph.D., F.R.S.
1894-1896.	HENRY WILDE, D.C.L., F.R.S.

*Elected April 28th; resigned office May 5th.

Date of Election.	
1896.	EDWARD SCHUNCK, Ph.D., F.R.S.
1897-1899.	JAMES COSMO MELVILL, M.A., F.L.S.
1899-1901.	HORACE LAMB, M.A., F.R.S.
1901-1903.	CHARLES BAILEY, M.Sc., F.L.S.
1903-1905.	W. BOYD DAWKINS, M.A., D.Sc., F.R.S.
1905-1907.	Sir WILLIAM H. BAILEY, M.I.Mech.E.
1907-1909.	HAROLD BAILY DIXON, M.A., F.R.S.
1909-1911.	FRANCIS JONES, M.Sc., F.R.S.E.
1911-1913.	F. E. WEISS, D.Sc., F.L.S.
1913-1915.	FRANCIS NICHOLSON, F.Z.S.
1915-1917.	SYDNEY J. HICKSON, M.A., D.Sc., F.R.S.
1917-1919.	WILLIAM THOMSON, F.R.S.E., F.C.S., F.I.C.
1919.	G. ELLIOT SMITH, M.A., M.D., F.R.S.
1919-1921.	Sir HENRY A. MIERS, M.A. D.Sc., F.R.S.
1921-1923.	T. A. COWARD, M.Sc., F.Z.S., F.E.S.
1923-1925.	H. B. DIXON, C.B.E., M.A., Ph.D., M.Sc., F.R.S., F.C.S.
*1925.	Rev. A. L. CORTIE, S.J., D.Sc., F.R.A.S., F.Inst. P.
1925-1927	H. LEVINSTEIN, D.Sc., M.Sc., F.I.C.
1927-1929.	W. L. BRAGG, O.B.E., M.A., F.R.S.
1929-1931.	C. E. STROMEYER, O.B.E., M.Inst.C.E.

LIST OF HONORARY MEMBERS OF THE SOCIETY.

Date of Election.	
Apr. 26th, 1892.	C. LIEBERMANN.
Apr. 17th, 1894.	J. W. L. GLAISHER.
do.	A. GOUY.
do.	SIDNEY VINES.
do.	EMIL WARBURG.
Apr. 30th, 1895.	SIR JOSEPH JOHN THOMSON, O.M.
Apr. 24th, 1900.	SIR J. ALFRED EWING.
do.	ANDREW RUSSELL FORSYTH.
do.	ROBERT RIDGEWAY.
May 13th, 1902.	SIR JOSEPH LARMOR.
do.	SIR OLIVER LODGE.
do.	HENRY FAIRFIELD OSBORN.
do.	DUKINFIELD HENRY SCOTT.
Apr. 28th, 1903.	FRANK WIGGLESWORTH CLARK.
Apr. 5th, 1910	WALTHER NERNST.

*Died May 16th, 1925.

Date of Election.	
Nov. 29th, 1921.	Sir HORACE LAMB.
do.	LORD RUTHERFORD, O.M.
do.	SIR ARTHUR SCHUSTER.
do.	G. ELLIOT SMITH.
Nov. 28th, 1922.	NIELS BOHR.
Apr. 13th, 1926.	SAMUEL ALEXANDER, O.M.
do.	ARNOLD SOMMERFELD.
Nov. 16th, 1926.	SIDNEY J. HICKSON.
do.	SIR HENRY A. MIERS.
May 13th, 1930.	F. E. WEISS.
Mar. 17th, 1931.	C. L. BARNES.

LIST OF CORRESPONDING MEMBERS OF THE SOCIETY.

Date of Election.	
Feb. 3rd, 1920.	WILLIAM SALVADOR CURPHEY.
Nov. 1st, 1921.	MRS. C. W. PALMER.
Nov. 29th, 1923.	H. F. COWARD.
Apr. 1st, 1924.	GILBERT J. FOWLER.
Dec. 16th, 1924.	G. SENN.
Oct. 13th, 1925.	H. G. A. HICKLING.

LIST OF ORDINARY MEMBERS OF THE SOCIETY.

Harold Adamson, Trafford House, Wilmslow, Cheshire.
Eric Ahlquist, 20 Victoria Avenue, Cheadle Hulme, Cheshire.
Miss A. C. Alexander, B.Sc., c/o Messrs. Tootal, Broadhurst Lee Co., Ltd., 56 Oxford Street, Manchester.
W. E. Alkins, M.Sc., West End Avenue, Leek, Staffs.
John Allan, F.C.S., 18 Moorfield Road, West Didsbury Manchester.
J. T. Allpass, 54 Daisy Bank Road, Victoria Park, Manchester.
W. Anderson, B.Sc., The College of Technology, Manchester.
Gerald Andrew, M.Sc., Egyptian University, Cairo.
W. H. Andrew, c/o "Reporter" Office, Market Square, Ashton-under-Lyne.
L. M. Angus-Butterworth, F.R.G.S., F.S.A., Lea Hurst, Dunham Massey, Cheshire.
G. E. Archer, M.B., Ch.B., West Thorpe, Park Road, Bowdon, Cheshire.

J. R. Ashworth. D.Sc., 55 King Street South, Rochdale.
Col. A. J. Bailey, C.B.E., J.P., Chaseley, Dunham Road, Bowdon, Cheshire.
F. W. Bailey, Haven House, Broadbottom, Cheshire.
Gustav Behrens, Holly Royde, Withington, Manchester.
W. H. Bentley, D.Sc., F.C.S., 25 Uppingham Road, Wallasey.
S. H. Bickham, F.L.S., Underdown, Ledbury.
A. E. H. Blackburn, Arncliffe, Eccles, Manchester.
R. W. Blakeley, 4 Seedley Park Road, Pendleton, Manchester.
Frank Bowman, M.A., M.Sc.Tech., 22 Chatham Grove, Withington, Manchester.
Capt. A. W. Boyd, M.C., M.A., F.E.S., Frandley House, Nr. Northwich.
A. J. Bradley, Ph.D., M.Sc., The University, Manchester.
His Honour Judge F. E. Bradley, M.A., LL.D., F.R.S.E., 8 Balmoral Road, St. Annes-on-the-Sea.
Professor W. L. Bragg, O.B.E., M.A., F.R.S., Nobel Laureate, 45 Pine Road, West Didsbury, Manchester.
J. Crighton Bramwell, M.A., M.D., F.R.C.P., Baguley House, Baguley, Cheshire.
J. C. M. Brentano, D.Sc., 7 Blair Road, Alexandra Park, Manchester.
J. H. Brierley, The Clough, Whitefield, Nr. Manchester.
L. J. F. Brimble, B.Sc., The University, Manchester.
F. J. Brown, M.Sc., The University, Manchester.
David Brownlie, B.Sc., A.I.Mech.E., F.C.S., 46 Grange Road, Ealing, London, W. 5.
H. E. Buckley. M.Sc., Bradda, Hazelhurst Road, Worsley, Lancs.
C. F. Budenberg, M.Sc., M.I.Mech.E., Somerville, Arkwright Road, Marple, Cheshire.
G. N. Burkhardt, M.Sc., Ph.D., F.I.C., The University, Manchester.
F. P. Burt, M.B.E., B.Sc., D.Sc., 15 Oak Road, Withington, Manchester.
W. Burton, M.A., F.C.S., 8 Primrose Hill Road, London, N.W. 3.
A. F. Campbell, M.Sc., F.C.S., F.I.C., Dyserth, Alkrington, Middleton.
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MEMOIRS AND PROCEEDINGS

OF THE

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MEMOIRS.

Contents.

NOTE.

I.—Greek Vases in the Manchester Museum.

By T. B. L. Webster.

The kindness of Dr. Carpenter and the late Miss W. M. Crompton enables me to give some account of the Greek vases in the Manchester Museum. The admirable photographs are the work of Dr. J. Wilfrid Jackson. Most of the collection of about 300 Greek vases were presented to the Museum by Mr. W. Sharp Ogden, others by Sir William Boyd Dawkins, and some of the best by the British Museum. It is true that there is no first rate vase of the best period of Athenian vase painting, but the collection has examples of most of the important fabrics and periods, and therefore it is possible to use the collection to illustrate the history of Greek vase painting.

Greek, as distinct from pre-Greek, vase painting starts in the tenth century B.C. The first phase, which lasts till about 700 B.C., is called the Geometric Period, because the painters decorate their vases chiefly with geometric ornament. The shapes are clear-cut and the parts defined, the glaze in which the patterns are painted is glossy and black, the patterns—mæanders, concentric circles, hatched triangles, etc.—form horizontal bands of decoration; these bands are arranged in a rhythmical sequence over the vase, the widest bands where the diameter of the body is greatest and the diameter of the neck is least; besides patterns, scenes of human life, burials, funeral games, battles, etc., sometimes fill these bands, and in them man is reduced to a mathematical symbol, triangular body, match-like legs, and things behind one another are shown side by side. Orderliness, rhythm, restraint are the characteristics of this style: it is contemporary with the writing of the Homeric poems, and is common to the whole of Greece and Greek Asia

Minor, though its full possibilities are only realised in the Dipylon style at Athens. In Manchester we have small examples from Attica (III. H. 1 and 2), Corinth (III. C. 1 and 2), and Smyrna (II. D. 5).

The seventh century is a period of disorderliness in politics and also of disorderliness in art. The desire for naturalistic representation breaks down the barriers of Geometric convention, and the Greek artist is helped in this direction by imported works of Oriental, Egyptian, Cretan, and Cyprian art. The common elements of this artistic revolution are these: the shapes flowing instead of sharply defined, the ornament curvilinear and naturalistic instead of rectilinear and abstract, and enlivened by the addition of red and white on the top of the black varnish, and lastly subordination of pattern to human and animal scenes. But Greek Asia Minor, Corinth, and Attica develop their own styles. In Greek Asia Minor, that is in Ionia, life is easier, land and trade are better than in the homeland: so we find already in the seventh century a luxurious style—the clay is bad, and therefore covered with a slip of fine white imported clay (meerschaum); the vases, mostly wine jugs, plates, and deep chalices, are decorated with friezes of animals, goats, deer, and birds; local variants of this style are produced at Rhodes, Ephesus, Miletus, Smyrna, and the Egyptian town of Naucratis. We have an excellent example, a big stemmed fruit dish from Rhodes (II. D. 2) and fragments of others from Naucratis (II. D. 9-14).[1] In the later phase of this style, which belongs to the early sixth century B.C., the animals are in silhouette, and the details are done in incision: this is due to Corinthian influence, but before turning to Corinth notice a little aryballos or oil bottle (II. D. 3), and a thin cup (II. D. 6), which are of a less pretentious Ionian fabric.

In Corinth there is a gradual transition from the Geometric style to that of the seventh century (this period of Corinthian art is called proto-Corinthian, to distinguish it from the later Corinthian, which begins about 625 B.C.). We have two very fine jugs which show the change in ornamentation (III. C. 2

[1] Pl. I. 3. The two upper rows.

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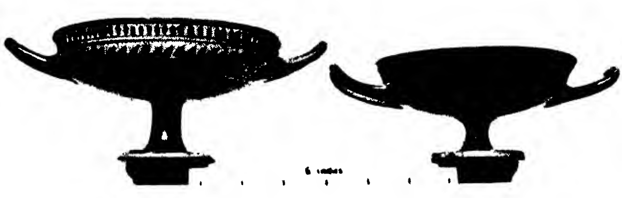

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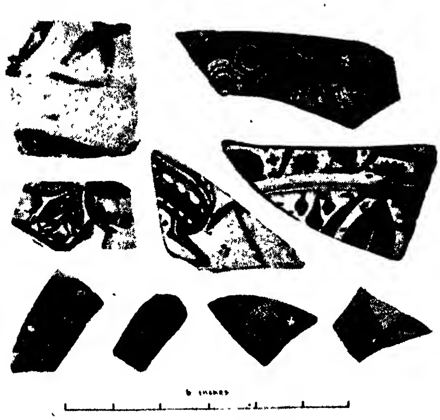

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PLATE I.

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and 3).[1] The change in shape can be seen best in the aryballos or oil bottle, the Greek equivalent for a soap box; in the seventh century the shape, which had been globular, becomes first egg-shaped and then pear-shaped, until it is so fine, that it will not stand but has to be suspended. There is one workshop which produces finer ware than any other, and is perhaps responsible for the introduction of a new technique. Marquetry and bronze work were flourishing industries in Corinth and produced inlaid furniture and vases. These Corinthian potters took from their colleagues the idea of painting the figures in silhouette instead of outline, and doing the inner-markings with incision. The particular potters of which we are speaking used brown-yellow for the human body and added red and black for details, but after this experiment in polychromy black became the established colour for the human body (except for women, who were painted in white), and red and white for details. In the second half of the sixth century proto-Corinthian gradually changes into what we normally call Corinthian: there are new shapes, notably the globular aryballos, much more comfortable to hold than the pear-shaped aryballos, and with a wide flat mouth, more practical than the small mouth of the early proto-Corinthian globular aryballos, and the alabastron or perfume bottle, a variant of an Egyptian shape. But there are changes also in decoration, the most noticable is the use of filling ornament in the background of the picture: there are two explanations: one is that the Corinthian potter was influenced by Eastern carpets, and there was plenty of trade between Corinth and the East; the other that the Corinthian potter did not like contrasts of black glaze and yellow-green clay, and therefore tried to give his vase a more uniform colouring so that the eye should not be distracted from the shape of the vase. Of this fabric we have excellent examples, e.g. the aryballos (III. C. 10), the alabastron (III. C. 29), the œnochœ (III. C. 46), the pyxis (III. C. 58); the female bust (III. C. 75) is one of the three handles of a round pyxis or box of the early sixth century B.C. There is a plainer fabric decorated in black with red bands:

[1] Pl. I. 1. The right-hand jug is later than the left; curvilinear snake on shoulder, colour contrast of black and white triangles.

we have a lekythos of a rare shape (III. C. 74). There is also a more elaborate fabric, mostly large vases, painted with mythical scenes: there is little filling ornament, the scenes are excellently composed, the figures are either black with incised lines, or white with black lines: the yellow-green Corinthian clay is often covered with a thin slip of red clay for the picture panel; this may be in imitation of the fine red clay of Attic vases at this period. We have a single jug of this period (the early sixth century B.C.), but a fine one with red slip, on it two riders, and at the back a large eye to frighten away evil spirits or men (III. C. 56).[1]

Attica was longer than Corinth in forging a new style after the break-up of the Geometric style, but by 570 B.C. her vases are serious rivals to Corinthian vases in the markets of Egypt, the Black Sea and Etruria, and by the end of the sixth century she has driven all competitors from the field. The Corinthian jug (III. C. 56) and two Attic vases, the cup or kotyle (III. H. 3) and the stemmed cup or kylix (III. H. 7) [2] are evidence of the competition in the early sixth century. The jug has, as has been said, a red slip in imitation of Attic ware; but this Corinthian shape was copied by Attic potters: we have a fragment from Naucratis (III. H. 36) [3] of an Attic olpe of this shape. The kotyle (III. H. 3) is of Corinthian shape; the panthers and the rosettes are of Corinthian type. The kylix (III. H. 7) differs from most Athenian cups in having the whole of the outside of the bowl covered with patterns; but there is a class of cup which was made at Sparta, probably also at Cyrene, and widely exported, which is similarly decorated, and it has been suggested that our cup and others like it were made to sell to customers who liked the Spartan cups. In those three vases we see the effect of Athenian, Corinthian, and Spartan competition at the beginning of the sixth century.

The black-figure style lasted in Attica from 600 B.C. to about 480 B.C. (though a special class of vases, the Panathenaic amphoræ, which were given as prizes at the Panathenaic games, were always painted in this technique). It is at its best from 550 B.C. to 500 B.C. We have no good examples; the

[1] Pl. II. 1. [2] Pl. I. 2, left. [3] Pl. I. 3, bottom, left.

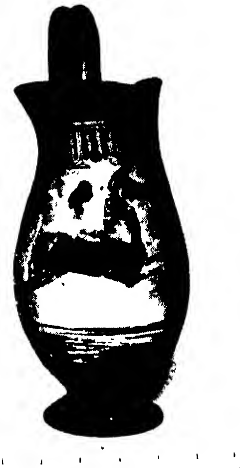

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PLATE II.

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early neck amphora (III. H. 4) and the early hydria (III. H. 5) have both been villainously painted over in modern times. But we have a fragment [1] from Naucratis (III. H. 38) which comes from a large vase by one of the best black-figure painters: on it we see the short chiton and the thigh armour of a Greek warrior; the chiton is red, the folds are rendered in incised lines, the curls on the thigh armour are rendered in incised lines with a white dot at the end of the curl. But though this is the only fragment of a first-rate vase, the long series of lekythoi give us some idea of the development of the style: these little vases, perfume pots, were commonly used for offerings at tombs and the series ends in the beautiful white ground lekythoi of the fifth century (of these last we have a single example but the decoration has vanished, III. I. 7). In shape the development can be traced from such lekythoi as the early one (III. C. 74) to the ordinary black-figure type, e.g. III. H. 14. In the Attic lekythos the parts are again sharply defined, mouth, neck, body, foot: we have reached another orderly age, the age of Peisistratos and his sons, and its ideals of shape are akin to those of the Geometric period. But there is a great advance in the technique of drawing; though bodies are still normally frontal and heads and legs in profile, the drapery is no longer flat but the folds are indicated. The artist is on the way to represent three dimensions. Before he can do that, another technical change is necessary. On the lekythos (III. H. 14) two bearded men are seated on the ground conversing; their legs are wrapped in their cloaks; they have wreaths on their heads. On another lekythos in Manchester (III. H. 24), the finest although its mouth is missing, two satyrs with red tails and beards, one with a knife in his hand, are stealing up to a goat, in the background is a vine with clusters of grapes. Satyrs are the servants of Dionysus, the god of wine; goats damage vineyards and therefore must be punished. This lekythos has a white slip like the Ionian vases of the seventh century: this became popular in Attica about 530 B.C., and lasted for lekythoi through the fifth century.

About 530 B.C. a technical change was made: hitherto

[1] Pl. I. 3, bottom, second from left.

vases had had black figures painted on the red clay, now the vase was painted black and the figures left in the red of the clay. This is called the red-figured style: the inner markings are done in black or brown. This had several advantages: the vase shape showed better when the vase was black (and some of the most beautiful vases of the fifth and fourth century are those which are glazed black and have no decoration at all, for instance our cup, III. L. 35:[1] this can be dated about 450 B.C.; the stemless cup, III. H. 10, is earlier, about 500 B C.; the very fine cups with a small stamped pattern in the centre of the bowl, III. L. 40, 41, were made about 400 B.C.) Then the red figures on the black look solider than the black on the red; and not only is the varnish line for the inner markings more pliable than the incised line, there are two values of line, black and brown. Till about 480 B.C. black figure and red figure run parallel, then red figure holds the field. These years are the history of the gradual conquest of the problems of drawing, the problem of representing a figure not as an aggregate, head, body, legs, but as a whole, the problem of perspective, the problem of representing character and emotions. The material in Manchester only allows us to suggest, not to trace this development. The painter of the column krater (III. I. 3), a large bowl used for mixing wine and water, is confident enough to draw the warrior who is leaving home with his body and legs in full face. The hydria (III. I. 1) shows a typical interior scene.[2] The painter of the pyxis or box (III. I. 2)[3] has shown excitement in the faces of his figures: I am not sure what the scene is, I think it is the birth of the first child. The nurse holds the baby, the mother and the father stand by, a woman runs with a thurible in her hand, Zeus, Aphrodite, and the god of marriage look on. These are vases of about 470 B.C. In the little œnochœ (jug) with the young satyr stealing up to a wine jug (III. I. 15) the drawing is perfectly free. The excellent hydria (III. I. 5),[4] which was painted about 370 B.C., introduces us to a new problem: the drawing is brilliant, a mænad leans on a pillar, a Pan and a satyr steal up to attack a second mænad, who is seated. The scene is common

[1] Pl. I. 2, right.
[2] Pl. II. 2.
[3] Pl. II. 4.
[4] Pl. II. 3.

and goes back at least to the middle of the sixth century B.C. But here the pillar and the seated mænad are painted in white. In our vase this does not offend : in other vases when there is more white it is far more disturbing. What has happened is this. From the beginning of vase painting until about 470 B.C. the vase painter is on a level with the fresco painter. But when the painter masters perspective, and when, further, he masters shading and gradation of colour, and we have literary evidence that this happened in the second half of the fifth century B.C., and that at the end of the century there was actually an illusionistic school, to which Plato vigorously objected, the vase painter can't follow—he can't compose three-dimensional pictures because he is confined to the rounded surface of the pot, and he can't use shading and colour because he is confined to his black varnish line. Vases such as ours represent the attempt of the vase painter to do something of what the painter of pictures is doing. Other schools, noticeably the South Italian schools, went further than the Athenian in this respect, and plastered their vases with yellow and white ; there are a good many examples in the Manchester Museum : one lekythos (IV. C. 9) has an Eros riding a dolphin, beautifully drawn. But however interesting their vases may be for the subjects represented (many of them throw a light on lost tragedies), as vase painting they are inferior : the drawing is coarse, the colours are unpleasant, and the painters have no respect for the form of the vase.

Apart from the Attic vases of the fourth century, of which we have an excellent early example in the hydria quoted above, the plain black varnished vases are the most interesting, though even there the shapes are not so good as in the fifth century : they are taller and less practical ; the handles are twisted ; the strength of the classical period has gone. But there is a last flowering—the Gnathia ware of the third century B.C.—this was produced at various centres in South Italy, and we have several excellent examples. One of the best is a bell krater (mixing bowl), all black except for ivy sprays in white.

II.—The New Mounting of the Large Rowland Concave Grating at the Physical Laboratories, Manchester University.

By W. LOCHTE-HOLTGREVEN, D.Phil.

John Harling Fellow, Manchester University.

ONE of the finest pieces of optical apparatus in possession of the Manchester Physical Laboratories is the large Rowland Concave Grating which was selected for Sir Arthur Schuster by Prof. Rowland himself. The grating was set up in a room on the top floor of the physics building, the Rowland Mounting being employed, and many important researches were carried out with it. During the past twenty years the researches in optics have been rather overshadowed by the well-known studies of crystal structure by the method of X-ray reflection. The rapid development in spectroscopy during this period has revealed the structure and significance of atomic spectra, and has also led to a fairly complete understanding of the properties of diatomic molecules, whilst very recently many important researches have shown that spectroscopic methods can be successfully applied to the study of polyatomic molecules. The two branches of Physics, analysis of crystal structure and spectroscopy, are thus tending to become closely connected with each other, and hence it seemed desirable that the optical apparatus of the laboratories should be restored to active service.

The existing mounting of the large grating did not appear to be quite satisfactory for the new problem. Molecular spectra are generally far weaker than atomic spectra and thus involve much longer exposures, and this increase of exposure imposes new conditions on the mounting. The grating must be kept at a constant temperature and must also be free from

vibration over long periods. The original mounting on the top floor could not fulfil these new demands, and it was decided therefore to set up the grating in a new mounting.

In considering the advantages of the different types of mounting which have been devised for a large Rowland concave grating the following points seemed to be of great importance. The experimental production of molecular spectra involves an extended and complicated technique, and this renders it very desirable to photograph the whole of an interesting spectral range with one exposure (if necessary even in different orders simultaneously), and to avoid all trouble with adjustment of the spectrograph. This precludes the use of any mounting having different adjustments for different parts of the spectrum. A further requirement is the absolute rigidity of the whole mounting, and this excludes any mounting which employs a moving camera or grating holder. The ideal mounting would thus appear to be a solidly constructed circle, of the size of the Rowland circle, on which the grating and slit would be mounted in their appropriate positions. The existence of the whole circle allows the use of each side of the grating and of the highest order spectra which the grating can give. Such mountings have been constructed, but only for small gratings. For a very large grating, however, the complete circle is inconvenient, because of its size; and also the region of the very high orders becomes less important because of the rapid decrease in intensity. Consequently only a part of the circle (approximately half the circle) is required. This leads to the mounting which was first used and developed by Runge and Paschen, and which has been adopted with some modifications for the present mounting.

A suitable room which would allow a solid mounting of the grating upon the foundations of the building and which could also be easily kept at a constant temperature was found to be a room on the basement floor situated on the north side of the main Physics block. This room, measuring 23 × 35 ft., was divided, by means of a heat insulating partition, into two rooms, one of which is used for the mounting, whilst the other contains the necessary apparatus for the light source. The dividing wall is pierced with an opening in which is placed

the slit. In this way the grating may be protected from any rise in temperature consequent upon operating the light source.

The general situation of the rooms is indicated in Fig. 1. The heatproof wall consists of a double layer of "celotex," enclosing a two-inch layer of air. The windows are also fitted

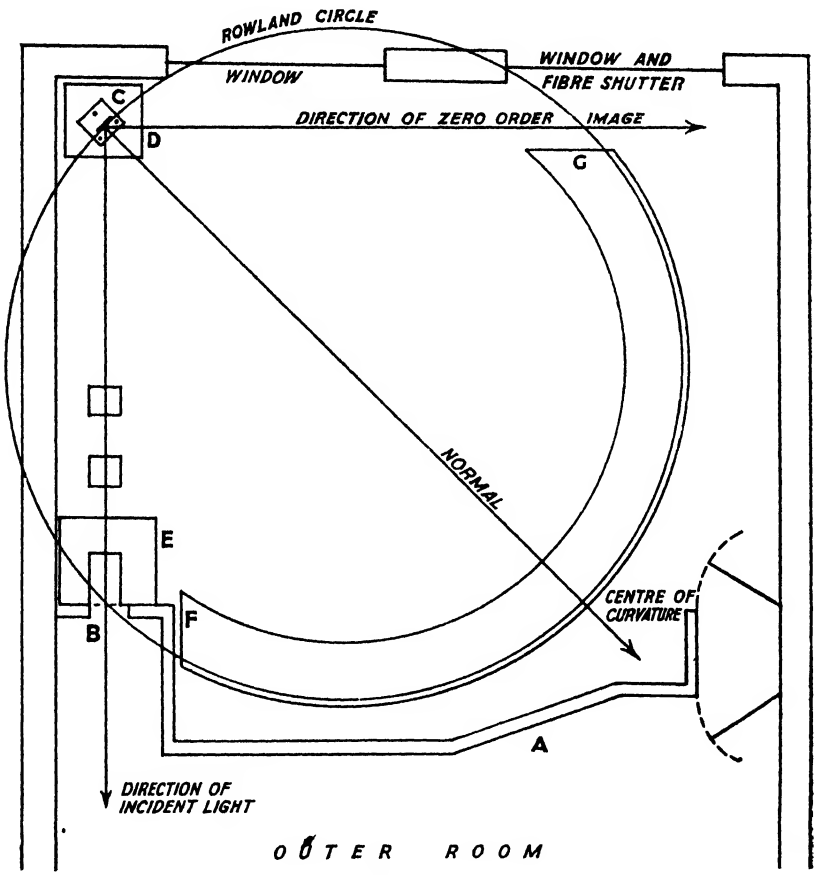

FIG. 1.

with shutters of "celotex." A double door allows one to enter the grating room without light being admitted. In order to obtain the necessary constancy of temperature, all steam heating radiators and pipes have been removed. An electrical heating installation has been fitted, which can be operated from without. This consists of four heating elements,

each with an area of about 5 sq. ft., in order to obtain a uniform distribution of heat. In addition, a continuous circulation is provided by a large fan suspended from the ceiling. An automatic thermostatic control can easily be added, but from experience during the last month the temperature of the room seems to remain sufficiently constant to enable us to get well defined second order photographs with exposure times of about one week without the use of a special automatic control.

The grating itself possesses a radius of curvature of 21 ft. 6 ins., with a ruled surface 15 × 5 cm., the total number of lines being 88,500, i.e. 14,438 lines to the inch. It is mounted in the original holder, which is further attached to a very heavy lead base supported by three levelling screws. A glass plate slides in the frame immediately in front of the grating surface and thus protects the grating when not in use, being removed only during exposures. The whole of the grating holder can, in addition, be covered by a large protecting copper box, which fits upon a wooden base. The grating stands on a massive brick pillar in one corner of the room and six similar pillars support the stonework platform which carries the plate-holding arrangement. The Rowland circle, 21 ft. 6 ins. in diameter, is indicated in Fig. 1. On this circle the slit and grating are placed, and the stone platform for the plate-holders follows the same circle. The camera device consists of two stainless steel strips $\frac{3}{16} \times 1{\cdot}5$ ins. and 28 ft. long, which are carried by a series of 20 iron clamps (Pl. I) at intervals of 1 ft., which are attached to the stone platform.

The rails are supported, one vertically above the other, being separated by a distance of 4 cm., and both are constrained to lie on the Rowland circle by the action of the clamps. The photographic plates are pressed against the outer side of the rails, with their sensitive side towards the grating, by small holders, and thus a surface 4 cm. wide is exposed. With this arrangement, plates of any length may be placed at any desired point of the Rowland circle and bent into the same curvature. The rails and clamps are of very robust design, and consequently the camera arrangement is rendered very rigid. Thus the rails are unaffected by the tension in the bent plates, and we are able to remove or insert a plate at any point with-

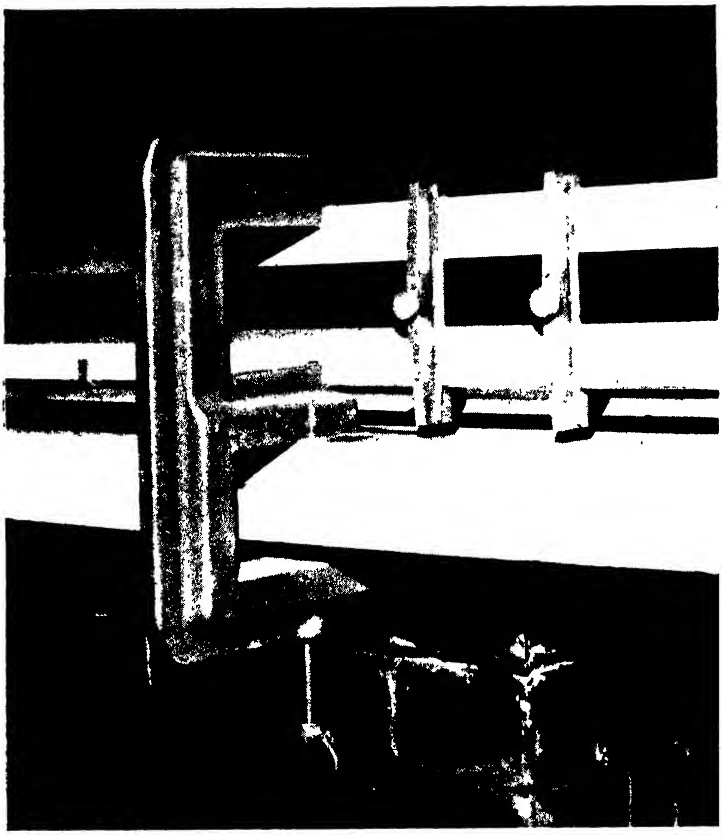

Plate I.

Camera device for the Rowland Concave Grating. Portion of the stone platform showing a clamp holding the rails. Photographic plates may be fastened to the rails by means of small clamps (right of the picture).

[*To face page* 12.

out disturbing any other plates which may be being exposed. This proves to be very useful for controlling the spectral conditions during long exposures in higher orders by means of first order plates.

The slit, which was also part of the original equipment, is mounted in a massive iron frame, which is cemented to a stone pillar similar to that supporting the grating and also lies on the Rowland circle. The slit holder is so constructed that the slit may be moved in a horizontal plane towards or away from the grating, also up and down in a vertical line, and finally may be rotated in its own plane.

The Rowland Circle has been roughly calibrated, and the wave-length at any point, expressed in terms of the first order, is indicated by a scale beneath the rails. For the exact determination of the wave-lengths of spectral lines, however, a standard spectrum must be photographed in addition, and this, for convenience, is partly superposed on the spectrum in question. On account of the astigmatism of the concave grating this cannot be done, as in the case of a prism spectrograph, by covering a portion of the slit, but a portion of the plate must be screened from the light. On this portion the standard spectrum is photographed, whilst the former portion of the plate is covered. In the present arrangement a system of 14 diaphragms is employed by means of which either the upper or lower part of the plate may be screened. Each of these consists essentially of a blackened piece of Al foil (1·5 × 24 ins.) supported parallel and close to the rails by three horizontal wires fixed to an iron "rocker." The "rockers" are operated by a wire attached to a lever which passes to the outside of the grating room and thus the screens may be raised or lowered without actually entering the grating room. Any diaphragm may be easily removed should the whole width of the plate be required (Fig. 2).

In order to obtain well defined lines the rails supporting the photopraphic plates must be exactly on the Rowland Circle and this presents the main difficulty of the adjustment. The following method was employed. Small photographic plates were exposed between the rails at an angle of about 45 degrees with the vertical (Fig. 3).

Thus successive horizontal sections lie at different distances from the grating. A spectral line obtained on such a plate

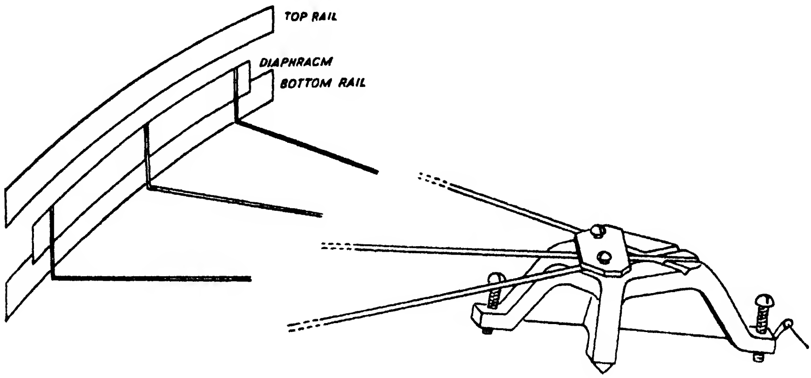

FIG. 2.

appears sharp only in the neighbourhood of the exact focus and broadens out quickly towards both ends as the definition alters very rapidly with the distance from the grating. The

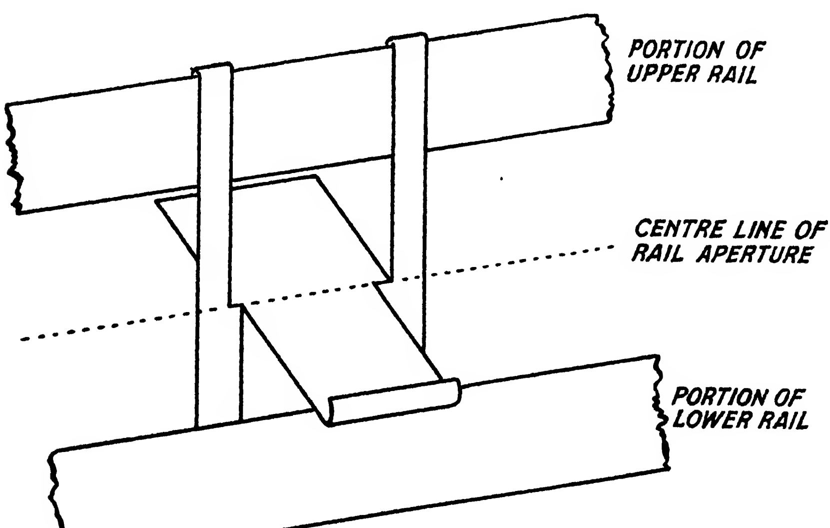

FIG. 3.

length of the well defined part of the line was about 4 mm. and thus the centre corresponding to the true focus could be obtained with an error less than 1 mm. From a series

of such plates taken at equal distances round the circle the variation of the focus at every point could be determined. The clamps were then moved along the radii and the rails gradually brought into the best position.

It is an interesting fact that the lines outside the correct focus do not merely broaden, but split up into four components. This spurious "fine structure" appears to be independent of the wavelength and of the order, thus indicating a property of the grating itself. To investigate the point we have covered the middle portion of the grating by means of a vertical diaphragm. The outer parts of the grating may then be considered as two distinct gratings with slightly different positions of their normals. The lines produced by these two gratings coincide only on the Rowland Circle; consequently upon an inclined plate at this point two intersecting lines will be formed, the point of intersection lying on the Rowland Circle. The above fourfold fine structure, found outside the focus with the grating uncovered, indicates therefore that there are four vertical zones of the ruled surface having high reflecting power, alternating with less effective zones.

The distribution of intensity in the spectrum formed by a diffraction grating is conditioned by the form of the ruling. The intensity of a certain spectral region changes from order to order with the angle of diffraction, and this variation is usually different for different regions of the spectrum. Thus we may have a certain order possessing the strongest violet spectrum, whilst another order possesses the strongest red. In the present arrangement it is found that the violet portion of the second order is about twice as strong as the corresponding part of the first order spectrum. The angle of incidence is 45° and a different distribution of intensity could be produced by changing this angle. This can easily be done by providing another slit. The writer has used three different slits with a similar mounting and has found this to be extremely useful.

The grating being one of the original Rowland gratings produces spectra of similar intensity on either side of the zero order. It differs in this respect from the gratings recently

of electric arcs. This consists of a main ventilating pipe suspended from the ceiling and fitted with four junctions situated at suitable points of the room. To these junctions may be attached vertical pipes immediately above the arc, the fumes of which are drawn up the pipe and are passed into a ventilating shaft of the building by means of an electric fan.

I wish to express my sincere thanks to Professor W. L. Bragg who has rendered possible my stay in Manchester and has arranged all the necessary alterations to the room; to Dr. Lowery of the College of Technology who provided all the special fittings of the mounting which were constructed under the supervision of Mr. Liversidge in the workshop of the College. Dr. Lowery has also kindly loaned the transformer and other pieces of apparatus. I wish finally to thank Mr. E. Eastwood for his assistance in the fitting and adjustment of the whole apparatus.

III.—The Psychology of Musical Appreciation.

(Being the Sixth Joule Memorial Lecture.)

By C. S. Myers, C.B.E., (Hon.) D.Sc. (Manch.), F.R.S.

In his book entitled *Musical Composition* the late Sir Charles Stanford relates (p. 143) how, at the age of fourteen, he vainly tried to set to music a long dramatic poem but had to abandon his attempt when he came to tackle the fourth verse of it. But, meeting with the same poem once again when he was ten or eleven years older, he sat down and composed music for the whole of it straight away without any difficulty. An identical interval has passed since last I published anything concerning the psychology of musical appreciation. Like Stanford, I have not pursued this subject during the interval. And now that I have been induced to reconsider it, I wonder whether, like him, I shall be able to achieve my aim with improved success. In one important respect, however, our conditions differ. When Stanford met with his poem for the second time, he had completely forgotten about his previous attempt. Indeed it was not until fourteen years after his song had been written and published that he came across his imperfect juvenile effort in an old box, when he discovered to his surprise that the music to the first three verses which he had then written was vitually identical in melody and harmony with his later, maturer composition. I, on the contrary, in preparing this address, have had before me the published results of my previous work carried on for twenty-five years between 1898 and 1922, which was concerned with primitive music and rhythm, with synæsthesia, and with individual differences in listening to tones and music.[1]

[1] For references to these publications, see note at the end of this address.

I can only hope that in reviewing and trying to integrate these past researches, the same influences of maturer age and thought, the same unconscious processes of consolidation and the same removal of any unfavourable inhibitions may be operative.

It seems to me that we can most profitably approach the subject of musical appreciation by considering the probable stages in mental evolution which have enabled man to experience music as he does, and the earliest functions which human music appears to have served. Accordingly, I will begin by describing the following reported case. A gifted musician was helping one day at a local opera in a performance of *Der fliegende Holländer*, when suddenly, at the end of Senta's ballad in the second act, the music became for him a series of extremely unpleasant sounds—not mere dissonances but the most intolerable noise. He left the theatre in tears. On the following day he happened to hear a barrel organ playing in the street, but again the tune seemed to him only utter noise. He could, however, still appreciate rhythm in dance music, and he could still read music from a written score as well as ever; but whatever he heard was but a toneless noise. I will not stay to discuss the cause of this condition, but it may be regarded, not fancifully I think, as a reversion to a far distant pre-vertebrate stage at which tones could not be discriminated from noises.

When in the course of evolution tones had begun to be discriminated as such, further improvements must have followed in the awareness of finer differences between them in respect of such qualities as pitch, timbre, loudness, etc. It is noteworthy that, especially by the less musical among us, these qualities still tend to be confused: a loud tone is judged by the most unmusical to be of higher pitch than when it is sounded softly, and a tone rich in higher overtones appears to all of us as higher in pitch than one of the same pitch which is of different timbre because it is poorer in such overtones.

In the cries of different animals we find all the material actually used in the music of various primitive peoples of the human species. The cries of some animals are charac-

terised by their glissando character where well-defined pitch is hardly discernible, of others by the use of small distances between successive notes, and yet of others by the use of intervals which appear to us approximately "consonant."

An important step making possible the evolution of music in man appears to have been the appreciation of equal tone distances: some of the most primitive examples of human music consist in a phrase of two, three or more descending tones separated by small, more or less definite and equal distances one from the other. Then came an important development based on absolute pitch, which also arose early in animal life—long before names were given by man to tones of different pitch. It has been observed that when parrots are taught a tune, they will always repeat it in the same absolute pitch; and this is said to hold often for young children. Certain musical instruments, too, such as the pan-pipes and the harmonica, which have a wide distribution throughout the world, the former, e.g. occurring both in Melanesia and in Brazil, the latter both in Burma and in Africa, have been found, despite their wide wanderings, to retain the same pitch. This is probably in part due to the early influence, in primitive man, of absolute pitch. In the construction of tunes, absolute pitch has been important in permitting the pitch of one note to be retained in memory, and thus to serve as a primitive key note. In savage music it is sometimes the first, sometimes the last note, which plays this rôle, influencing the number of descending steps and ensuring that the melody as it recurs in the song shall always recommence or terminate on the same tone.

There can be little doubt that the memory for absolute pitch is also responsible for the development of tone *intervals* as contrasted with tone *distances*. Tone intervals are based on the experience of 'harmony' between two successive tones, the remembered pitch of the first tone appearing in a certain degree 'harmonious' with the heard pitch of the following tone. Whereas the tone distances first employed in primitive music were narrow, the tone intervals, on the contrary, were relatively wide. But these relatively wide intervals arose through an awareness of harmony, not from the

summation of small tone distances, although later they were broken up to give rise to a series of smaller tone intervals.

Our own tone intervals are so often experienced through the *simultaneous* sounding of the two tones constituting any interval, that it is generally supposed that their selection has been due to the 'degree of consonance' or 'fusion' experienced when two tones of different pitch are sounded together. But many primitive peoples who use harmonious intervals sing only in unison, and these intervals occur in the songs of peoples who employ no musical instruments and hence no instrumental accompaniment whatever. The first use of tone intervals seems therefore to depend on the pleasure derived from the relation of two *consecutive* tones, not from the consonant effects of fusion obtained by hearing the two tones *simultaneously*.

It is obvious that the memory for absolute pitch has played an essential part in developing this relation. Indeed musical instruments, so far from developing the appreciation of harmonious (or consonant) *intervals*, have often helped to maintain scales based on tone *distances*. Thus the Siamese and Javanese instrumental scales divide the octave into seven and five *equal* steps, respectively; and our own pianoforte scale consists of twelve *equal* semitones,—a method of tempering which was independently adopted or advocated also in Indian and Chinese music. The ancient Greeks, too, appeared to have formed their scale by adding note after note or by joining tetrachord to tetrachord on their instruments. Indeed they gave a different letter-name to each note, ranging from α to ω; only in Byzantine times was the note following η given the name of α,—the identity of octave tones being at length recognized by identity of lettering.

Some years ago, the essential distinction between tone distances and the fusion effects of tone intervals was demonstrated by the description of a case of disordered hearing, in which the apparent pitch of a certain note was so lowered that its *distance* from another note, when they were sounded *successively*, was judged by the patient to be much reduced; but when the same two notes were sounded *together*, the true *interval* was at once correctly reported.

Not only does each tone, or each successive tone relation, develop its own significance, but also a definite 'musical meaning' is acquired by a whole group of successive tones when integrated and appreciated as a pattern, phrase or melody. Cases have been reported where the ability to hear noises and tones and to distinguish different pitches and timbres has been retained, but musical meaning has been suddenly and entirely lost. "I hear well," said such a patient, "I hear everything, but it is all a jumble." When a selection from a familiar opera was played to him, he was quite unable to recognize it. Finally, with mental development and experience, we reach the ability to appreciate, and to analyse, the component parts and the construction of polyphonic, e.g. fugal and contrapuntal, music.

The music of some extremely primitive peoples is distinguished by its *récitatif* character, that of others by its rhythmical character. In the former case it is closely related to speech, in the latter to movements of the limbs and trunk. In the former case its usual function is to add to the feelings conveyed by language in song, in the latter case to induce and to add to the pleasures of regularly recurring bodily movements. Could we but trace speech and music far enough back we might conceivably reach a common origin in sounds conveying a pre-linguistic meaning, an almost wholly affective non-cognitive meaning,—neither verbal nor musical, but comparable to those vocal expressions of contentment, pain, alarm, anger, lust, etc., with which we are familiar in infra-human animal life. From such an origin may have arisen in one direction the irregular, continuous changes of pitch (and rhythm) and the largely cognitive, utilitarian meaning characteristic of prose language, and, in the other direction, the regular, interrupted changes of pitch and rhythm and the largely affective, non-utilitarian meaning characteristic of music. If we may very broadly define meaning as what a stimulus or a definite series of stimuli or a state of consciousness stands for, that is to say what movements or conscious experiences it tends to call forth, then the meaning of a single written word consists in the *cognitive* ideas and images and consequent actions aroused by it; the meaning of a word or

sentence spoken in a voice, say, of anger or contempt consists besides in the *affective* recognitions or experiences produced; whilst the meaning of a heard musical phrase consists primarily in the emotional and other *affective* mental processes and in the impulses to movement which it evokes, and in the cognitive awareness of its structure.

There are also secondary cognitive meanings in music derived indirectly and personally from suggestion and association, and more directly and universally from the intellectual process of analysing its increasingly complex structure. Beyond this, however, music conveys no meaning. What we call to-day 'programme' music utterly fails to achieve its mistaken aim of communicating concrete, objective situations and specific acts,—unless the hearer is expressly supplied with a programme verbally describing to him what cognitive experience and activities the music which he is about to hear is intended to represent. But all music, whether it be programme music or pure ('abstract') music, succeeds in evoking very broadly similar appreciations of its structure and similar affective experiences in different members of an audience, producing joy or sorrow, appearing harsh or tender, or being soothing or exciting, and thus evoking corresponding visceral, glandular, circulatory, respiratory and other bodily movements among those of average musical ability who listen to it.

More or less artificially, we may divide the enjoyment of music into the enjoyment of sound, the enjoyment of tune, and the enjoyment of rhythm, although few musical tunes are ever wholly devoid of rhythm, few musical rhythms are ever wholly devoid of tune, and neither can be said to be ever devoid of sound. The effects of melody are different from those of rhythm, for melody and rhythm, as we have seen, serve different purposes, and the appreciation and enjoyment of each differ in different individuals. But the complex developments which they have undergone are essentially similar. Just as the enjoyment of melody has been enhanced by the simultaneous combination of different melodies or other accompaniments, or by variations in the melody, especially as practised in advanced European music, so too the enjoyment of rhythm has been enhanced by the simultan-

eous opposition of different rhythms or by complex changes in rhythm, especially as developed (to an amazing degree) among certain primitive peoples. Alike in the higher development of harmony and of rhythm, and for the full comprehension of musical thought, the intellectual acts of synthesis and analysis are required.

It is already clear that music has had various fundamentally different relations in its past history. It may be related to speech; it may be closely associated with bodily movements, especially with work-a-day movements and with rhythmical movements,—with dancing in particular; and there can be no doubt that it may also be intimately connected with sexual feeling and courtship. But it would be erroneous to say, as has often been variously said, that every kind of music has arisen from one source—from speech, or from rhythm, or from sexual activity. All one can truly say is that in its various appeals music is closely related to each of these. And thus it is that owing to individual mental differences the same music may show extraordinarily wide differences in its intellectual, motor and emotional effects on different individuals, and that different music may make different appeals to the same person.

We have now reached a stage in which we can examine and better interpret other wide individual differences which are found in listening to music. They consist, however, in differences rather of degree than of kind. Although we shall without difficulty be able to distinguish different kinds of attitude towards music, these different attitudes cannot be strictly and severally allocated to different individuals. In other words, we cannot say that an individual A exhibits solely an X type of attitude, an individual B exhibits solely a Y type of attitude, and so on. No one individual belongs to a pure type. All that we are warranted by our experimental evidence in saying is that in some persons one attitude predominates, in others another. Moreover, in a given individual, sometimes one attitude is predominant, whereas at other times and in other mental and musical circumstances a different one predominates. Let us realise, then, at the outset that the different kinds of attitude which we are about to

distinguish are not separately distributed, but vary in extent and employment both among different individuals and in the same individual under different conditions.

The first attitude in listening to music, to which I will draw attention, arises from what may be termed its *intra-subjective* appeal. It evokes in the listener sensory, emotional or other affective experiences and tends to arouse in him experiences of active or passive bodily movement or desires for or impulses to movement. Let me cite a few examples gathered from the introspections of certain persons who in my experiments listened to various pieces of music: " I felt a restful feeling throughout . . . like one of going downstream while swimming . . . I wanted to throw myself back and be carried along." " During the dance movement I . . . . . felt diaphanous things floating in the wind. . . . The breeze came in contact with my right cheek." " A circular movement. I was being turned round very slowly." " A great feeling of happiness, followed by expansion inside, leading to great excitement and breathlessness for a moment." " I felt the effect of being carried away, partly emotional, partly strain and tenseness of body."

The next attitude to which I wish to draw attention is closely related to and doubtless often derived from these sensory, affective and motor excitements. It may be ascribed to the *suggestive* appeal of music. Here we may meet with every stage between the simple colour images or synæsthesiæ relating to pitch, timbre and tonality, the passing associations due to similarity, and the elaborate day-dreams of phantasy. E.g. " I saw a beautiful grey, a lovely grey with light shadows . . . I saw another grey, just lovely, like glacier water . . . Don't you see the expanse, right on top of a hill? " " There she is," said another of my subjects, " the little fairy . . . Children dancing, not grown-up. . . . Men dressed in red with feather plumes. Don't you see the fairies? Yes. It's a sylvan sort of thing." " A cave, rocks, sea-waves . . . a sea-serpent poking its head out of the cave, dancing spray, with the sun on it. I could draw the exact picture."

The third attitude arises from the *critical* consideration of music. Here the listener is concerned neither with the

sensory, emotional or conative experiences, on the one hand, nor, on the other hand, with the suggestive images evoked in the two previous attitudes to music which we have been considering. He regards the music as something of worth, critically appraising the standard which he considers it to reach, its merit and its value. " It was a mere mechanical imitation . . . ," said one of my subjects, " like a painter imitating a great master." " I noticed the second horn was too loud . . . ," reported another; " when the second tune came with the 'cellos, it didn't stand out enough."

From this objective attitude we may pass to the fourth or *characterising* appeal of music. Here the music, instead of being criticised as an independent inanimate *object* of practical worth, is regarded as an independent, self-active *subject*, and is endowed usually with human qualities, such as joviality, playfulness, recklessness, daintiness, stupidity, insincerity, which personify it. " It tried to be light-hearted," said one of my subjects, " but it was all the time very sad." " There is something sinister about it." " The music seemed as if it were joking with me."

Sometimes the music is characterised not as an independent living being but as a self-active geometrical pattern. " It falls into a pattern . . . ," said one of my subjects. " Then came a pattern of a different type, beginning with zig-zags, obliquely transverse strands from lower left to upper right, going through a horizontally moving pattern." It is easy to see analogies between the forms and movements of such geometrical designs and the rising and falling pitch, the blending and segregation of different simultaneous themes, and the effects of various rhythms and syncopations in music. " Following the pattern," said one of my subjects, " is my greatest enjoyment in music. If I cannot follow it . . . there is no longer meaning in its movement." When, however, this subject can get no patterns of polyphonic or rhythmic origin to enjoy, when for example he is listening to a simple melody, he 'characterises' the music at once with such human qualities as langour, gloom, plaintiveness or menace.

Let us now deal with these four different appeals of music in closer detail, and with their inter-relations, taking the

characterising attitude first. It might be, and indeed it has been, thought that the characterising attitude originates 'empathically' from the intra-subjective attitude,—in other words, that a piece of music comes to be termed by the listener, say, high-spirited, just because it evokes high spirits in him. But that this is by no means necessarily the case is revealed by the following among many other similar reports of my subjects: "I noticed first the mournfulness of the music and then its effect on me." "The piece sounded cheerful in certain parts, but I felt in a contrary grain all the time." "I got the impression of people dancing, I think on the stage. . . . There was a note of sadness among the dancers, a sort of regretfulness. I think that the sadness affected me and came secondarily to the stage sadness." "It's all so intensely sad. All the time I was wondering whether it was cheap or not. I came to the conclusion that I ought to be moved. I *was* much moved by it after this conclusion."

It might similarly be thought likely that the characterising attitude was derived from the suggestive attitude, a tune being characterised, say, as trivial because of the triviality of the suggested ideas and images that it evoked. But, in point of fact, the converse is sometimes demonstrable, some human characteristic being first ascribed to the music and this characteristic then suggesting appropriate ideas and images. Sometimes the character aspect of the music and the train of ideas evoked develop side by side and distinct from each other. Thus to one of my subjects the music seemed trying to be persuasive, while the scene was imagined of a persuader and one who was to be persuaded: "There is no response to the persuasion: it is a failure. The characters disappear: and the music behaves like a Greek chorus, going over what has occurred in a philosophical manner." Sometimes, too, there is a blend of the character and intra-subjective attitudes. E.g. "I felt the yearning character of the first *motif*—a sense of tears in it—which was partly in the *motif* and partly in me."

We can hardly come to any other conclusion than that such characterisation of music is but a persistence of the primitive and deeply rooted tendency of mankind to personify

all natural objects, whether animate or inanimate, and to regard them as independent entities, wholly apart from their practical value or their import to or effect on the listener. It is indeed through this detachment from the human self of art-material and of its immediate experience, and through its contemplation for its own sake, that awareness of beauty becomes possible.

If characterisation is the attitude most favourable to æsthetic enjoyment, the intra-subjective and suggestive attitudes are most favourable for complete sensual and emotional surrender and for inducing a state of transport or ecstasy; while the critical attitude enters readily when the three other attitudes are impossible or are obstructed. When it is the resort of the expert, the critical attitude may facilitate, although it cannot induce, the experience of beauty. Among the less musical, it may, on the other hand, help merely to give music sufficient meaning to arouse the intra-subjective and suggestive attitudes. These latter attitudes are clearly and closely interrelated. The sensory, emotional, and motor effects of music tend to evoke trains of images and phantasies which in their turn, whether thus or directly aroused, contribute to the affective experience of the listener. When the listener surrenders himself to emotion and phantasy, any tendency to characterisation must inevitably be suppressed. But the temptation to such surrender is often resisted, as in the following example: "A distinctly pathetic ring about it. I should have felt distinctly wretched if I had got regularly into it, but I keep myself from this at a concert. I very rarely let myself go." Where, as among the most unmusical, the intra-subjective attitude is congenitally weak, the feeble sensory and affective responses aroused would not be expected to evoke trains of ideas and imagery. The suggestive attitude appears consequently to be rare among the extremely unmusical. But this same attitude is also rare among most highly trained musical people, because they tend to inhibit it largely owing to their adoption of the critical attitude. Thus one expert musician reported to me: "I now nearly always view music from the critical standpoint. I conduct: I compose. I always want to know how the conductor is

getting effects if it is a new work, and what will be his rendering if it is an old one." So he remarked of one composer: "I noticed by what simple means in these modern days he gets his effects. I noticed also . . . how he gathered up his climax by syncopation." And again—"As always in Beethoven, one must notice the tremendous . . . contrasts, especially dynamic contrasts. His *crescendos* always give me pleasure. Beethoven makes scale passages so much more interesting than, say, Liszt." Or once again, "As usual, the violinist uses too much *vibrato*. . . . The sweep up the strings made me feel quite sick."

It is highly interesting to observe that this same subject is nevertheless prone to characterisation and that he yields to it when, through dislike of, or lack of interest in the music, he is off his guard.: "The cadenzas are rather vulgar and horrid," he reported; "the introductory solo accompaniment . . . is in the last degree trivial." And when the music seems trivial, meretricious, 'stagey' or unreal, not only does its character appeal, but also its more lowly suggestive appeal, escape from suppression even among expert musicians. This same observer reported: "I opened this with a dog fight. . . . The opening of the second part was a dance of savages—*this is amazing to me*. I could see the red and blue round the loins. . . . *It is not like me at all*," he protested; "then, I think, I pulled myself together." "The beginning," reported another, highly artistic, subject, "reminded me of a stage, people coming on. It was trivial, theatrical." But see now what follows. "Then it passed to out-of-doors, real, not stage-like, in a wood, with sunlight, a vast procession of people slowly moving . . . with gold-coloured dresses, some green, all brilliant." So too another unaffected subject responded to "unreal" music—"I was up in the theatre, looking down." And yet another—"*I* felt no deep emotion. But there was much emotion in the *soldiers*."

May we not compare these various attitudes of the listener with the alternative attitudes of the actor who may be either dispassionately looking on while portraying the emotions of his part or, at the opposite extreme, so much more immersed in his part as to feel these emotions in himself? Similarly,

the listener to music may be so carried away as to feel emotion in himself; or he may, in the characterising attitude, as we have seen, attach the emotion to the personified music; or he may, in perhaps some intermediate way, attach it to some person or persons suggested by the music, as in the report of one subject who said: "I was in the Queen's Hall, a fair girl in a pink dress was playing and another girl was accompanying her. The violinist had a sad look about her. I felt she had had a sorrow in her life." "I cannot feel emotion in listening to music," observed one of my subjects, "unless I feel that I am moving in the same emotional attitude as the persons [imaged]."

In the exercise of the suggestive attitude, fairies, fauns and goblins may make their appearance—indicative of long-past juvenile imagination; lovers may appear, indicative of sexual influences; in warlike, barbaric or folk-tune music, soldiers, savages or villages are visualised, respectively; and in orchestral or religious music a concert hall, or church, a conductor, and one or more musical instruments may appear on the scene. What opportunity the interpretation of many of these forms and symbols of phantasy would provide for the psycho-analyst!

At first sight it may seem difficult to decide on the relative values of these four attitudes adopted in listening to music, when one of my subjects asserted: "Music always gives me the sight of so many charming things. That's why I like listening to it," whereas another insisted—"I always try and banish all imagination when listening to music," and yet a third reported—"Sometimes I listen to music seeing the orchestra and attending to the *technique*, sometimes enjoying visions of forests, etc., that come before me, sometimes paying regard to the meaning . . . etc., of the piece." The correct decision must surely be that through the sensations, emotions, actions, phantasies, patterns, colours, etc., which it arouses, music may give exquisite enjoyment, but that in addition music has an inherent meaning, inexpressible in terms of spoken language or felt emotion,—a meaning which becomes more and more clearly recognised, less affective, and more intellectual in character, the higher be the development of

musical appreciation and of musical composition. As one artistic subject of mine observed—"When I see the pictures [i.e. the ideas and images evoked] they take up almost all my attention, so that I have the feeling 'Dear me! I'm not listening,' and then I get back to the music." To his satisfaction one of my subjects reported—"The middle of the second movement [which he started to enjoy] switched me off my imagery and I returned to the pure consideration of the music." And another objected—"I cannot . . . conceive music *saying* anything"; and as yet another—a highly accomplished musician—explained; "Music has a meaning, but always in musical terms. I couldn't put it into words. It always irritates me to be asked to do this."

But if we admit that the highest appreciation of the highest music is to be derived from contemplation of the music itself rather than from mere surrender to its resulting emotions and suggestions, let us not lose sight of the originally manifold derivations and functions of music, viz. to express and to communicate emotions, to excite our imagination, and to induce rhythmical movements and other bodily, e.g. sexual and work-a-day, activities. And let us not make the mistake of assuming that the primary function of every art is to arouse an *æsthetic* experience,—the appreciation of beauty. For in its widest sense an art is a craft. No beauty is aroused in the practice of the art of medicine, seamanship and the like. From certain pictures or from certain buildings beauty *may* be evocable. But many pictures are merely portraits, that is to say copies of persons, or, as in the illustrated press, fulfil the function of recording events; and not all houses or factories can be so designed as to produce an æsthetic appeal. So it is with music. Music may be useful; it may be regarded from the practical point of view, say of dancing, marching or fighting, from the standpoint of its intra-subjective and suggestive effects, or from the critical consideration of its standard and value for the listener. But for the appreciation of its beauty the listener's personal and practical interest must cease. A certain psychical 'distance,' as it has been well termed, must be interposed. The sailor who is impelled to rescue the heroine in a melodrama by climbing down to

the stage from his seat in the gallery is psychically too 'near' the play to appreciate its beauty.

Clearly the characterising attitude marks an important approach towards the conditions of 'distancing' necessary for æsthetic appreciation. In it the listener regards the music as something existing quite independently of himself, and his experiences, and of his value and use of it. He no longer surrenders himself as a passive instrument to be played on, as it were, by the music. As one of my subjects averred—"To me music is never sad or joyful. I only get æsthetic impression." If he regards a composition as marvellously well-fitted to express its purpose, his critical attitude must be impersonal; that is to say, he must not regard the music as being well-fitted merely to give him enjoyment. If he regards it as ill-fitted, he will be debarred from readily finding beauty in it. If he finds it well-fitted, his experience of beauty may be enhanced by his admiration and wonder. But the mere realisation of appropriateness or perfection will not suffice to evoke an æsthetic experience. A thing of beauty must be viewed not as a satisfying piece of man-made mechanism, but as a 'distanced' living organic whole. And the adoption of the character attitude strongly favours this view.

But it is possible for us to 'distance' not only the music we hear, but likewise the phantasies, the feelings—even the sensations—to which it gives rise. And so, a day-dream evoked by music may itself become beautiful; a feeling of joy or sadness aroused may, by its 'individualisation,' itself become beautiful; while to the most sensual even the warmth of a bath may become beautiful,—if only it can be adequately 'distanced.' As one of my subjects insisted—"The special *feeling* I get from music makes it beautiful. It gives me a tender poetic feeling, almost pity." And as another explained,—"Certain short phrases give me quite a beautiful thrill, localised in the diaphragm—like the feeling that early morning brightness gives one." Thus beauty may still be appreciated in music, even although the æsthetically more lowly intra-subjective or suggestive attitude is adopted.

Are we then justified in concluding that we need not realise the musical meaning of a piece in order to obtain from music

æsthetic enjoyment? The answer in the affirmative to this question involves an examination of the term 'musical meaning.' I have already used 'meaning' in its widest sense, as being what any external object or state of consciousness stands for or prompts to. According to this broad use of the word, the peculiar auditory sensation of pitch produced in us by the middle 'c' ofthe pianoforte becomes the meaning of 256 to-and-fro movements or periodic vibrations of the air outside us; and the situation which confronts a duckling on its first sight of water has also a certain (extremely vague) meaning for the fledgling. But these are *innate* meanings common to and closely identical in all members of the same species. The more usual use of the term 'meaning' limits it to what has arisen through *acquired* experience and is confined to smaller numbers of any species. Thus the word 'elf' has meanings very different for the Englishman and for the German; and such an object as a motor car has meanings very different for the lady of fashion and for the engineering expert. Moreover, the term is usually applied to meanings which are fairly permanent, not to those which are established for temporary use and are to be later discarded, as, for example, the meaning of a knot tied in a pocket handkerchief for a reminder.

I propose to employ 'musical meaning' to the exclusion of any extreme possible uses of the term. I shall not apply it to sensory experience, common to and innate in all men, as the meaning of certain external vibrations in the air. Nor shall I apply it to the purely individual, rarely or never recurrent, associations, phantasies, or emotions which may be experienced on listening to music. Excluding these uses we are left with much in music that may be rightly said to have musical meaning,—much that is fairly permanent in the listener and is fairly common to a large number of listeners of the same musical ability and experience. We may, I think, correctly speak of the emotional musical meaning of a composition when it evokes some similar emotional response in large numbers of an audience. But unless the listener is absolutely devoid of musical ability, it has always at least some intellectual, in particular some formal, musical meaning, as well. Such meaning is given to music by the mere appre-

hension of the pattern of its melody or of its rhythm, as well as by the understanding of its polyphonic, fugal, or other formal complexity, or by the appreciation of the thought and the balance of the entire movement, sonata or symphony; and among the more musical it is essential for musical enjoyment.

Musical meaning enables a song to be enjoyed even when its words are sung in an incomprehensible language; as a Papuan once remarked to me when I asked him how he could appreciate a certain song, the music and words of which had been introduced to his island from another island, of the language of whose inhabitants he understood nothing—"It is not the words, but the music that counts." It is the difficulty in discovering the musical meaning of ultra-modern and exotic compositions, in addition to the repulsive unfamiliarity of new combinations and complications of tones and new musical idioms that prevents their initial appreciation. The violent criticism and opposition with which Mozart, Beethoven and Wagner first met is always repeating itself in the history of music. The meaning and hence the values of music are ever changing in appreciation.

So long as the listener (in his critical attitude) is worrying about the cognitive or intellectual meaning of music, it is impossible for him to enjoy it or to appreciate beauty in it. "No central idea in it," reported one of my subjects; "never knew where I was." Or as another said—"Too much bothered about finding meaning to be able to see any beauty." When the listener fails to find a meaning, his attention may *faute de mieux* revert to mere fleeting sensations, emotions, or images. Thus one subject reports "The whole has no meaning in the least to me. I don't understand it. I am catching hold of any image I can get." Some understanding at least, then, is necessary for the musician's enjoyment of music; otherwise what can at most happen is the mere enjoyment of sound,—the substance, not the form, of music.

We have seen how incompatible the character attitude is apt to be with the intra-subjective and suggestive attitudes, and the critical attitude with all the other three attitudes. We know that the repression of any incompatible mental process or attitude may be often successful: it will then lie

dormant and cause no trouble. Yet try as the more musical may to inhibit all emotion, phantasy, or characterisation in their desire to obtain æsthetic enjoyment from the intellectual contemplation of music, these are, as we have seen, never permanently kept under control but are ready to emerge from their repression whenever they have the opportunity to do so. The musician does not usually welcome the intrusion of 'associations.' Yet, as one of my subjects observed—" I object to these suggestions, for I find that the music . . . is not listened to for itself. But when the suggestions and the music absolutely blend, there is the completest and greatest enjoyment, greater than when there is music alone. They won't blend here," she adds, " because the dramatic scene will go on quite well independently of the music." And so we must conclude that the fullest and highest appreciation of music occurs when the whole of its varied and complex influences to which I have endeavoured to draw attention—when all the different attitudes which it may evoke—are in the most perfect harmony.

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IV.—" Unshared " Electrons and the Effects Produced by *o-p*-Directive Substituents in Organic Molecules.

By George Norman Burkhardt and
Meredith Gwynne Evans.

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The properties which have generally been ascribed to the so-called " unshared " electrons of such atoms as trivalent nitrogen, divalent oxygen and monovalent halogen cover a wide field and are of great importance. We propose to consider the essentials of the chemical view of these properties, bearing in mind certain recent changes in the theory of interatomic linkages. Taking the elements of the first series as the most clear-cut example, the formulæ

$$:\overset{\displaystyle R}{\underset{\displaystyle R}{\overset{\cdot\cdot}{\underset{\cdot\cdot}{N}}}}:R \qquad :\overset{\displaystyle R}{\overset{\cdot\cdot}{\underset{\cdot\cdot}{O}}}:R \qquad :\overset{\cdot\cdot}{\underset{\cdot\cdot}{F}}:R$$

must be taken to imply the following in order to meet the chemical requirements :—[1]

(1) The " unshared " electrons are normally not available for sharing with monovalent elements to form such compounds as NH_5 and NCl_5. This restriction will not apply to elements of the higher series which give rise to such compounds as PCl_5 and R_2SCl_2 unless these have structures of the type $(R_2SCl)Cl$.

[1] Quantum theory does not easily handle molecules more complex than NH_3, OH_2, Hal . H, but in order to limit the possibilities of ionisation and of molecular rearrangement it is often necessary for the organic chemist to consider only suitably substituted (usually alkylated) derivatives.

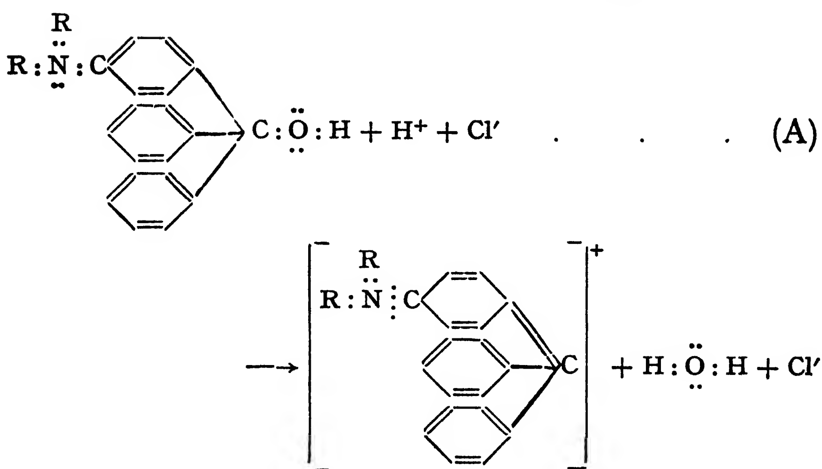
(2) These electrons, however, are more or less readily available for combination with atoms or ions which can reach a stable state and form a linkage of the covalent type by utilising these electrons in pairs, e.g.

$$:\overset{R}{\underset{R}{\ddot{N}}}:R \;+\; H^+ + Cl' \longrightarrow \left[H:\overset{R}{\underset{R}{\ddot{N}}}:R\right]^+ + Cl'$$

$$+ \;:\ddot{O} \longrightarrow :\ddot{O}:\overset{R}{\underset{R}{\ddot{N}}}:R$$

$$+ H:\overset{H}{\underset{H}{\ddot{C}}}:\ddot{I}: \longrightarrow \left[H:\overset{H}{\underset{H}{\ddot{C}}}:\overset{R}{\underset{R}{\ddot{N}}}:R\right]^+ + I'$$

$$3\;:NR_3 \;+\; CoCl_3 \longrightarrow \begin{array}{l} Cl.\quad .NR_3\\ Cl:\;Co\;:NR_3\\ Cl.\quad .NR_3\end{array}$$



(A)

The last two examples are directly analogous to the others.

(3) These "unshared" electrons become less readily available for forming linkages corresponding to the higher valency condition as one passes from Group V to Group VII

$$(\text{i.e.}\quad :NR_3 > :\ddot{O}R_2 > :\ddot{\underset{..}{F}}R),$$

and apparently in Groups VI and VII they become more readily available as one passes up the group to elements

of higher atomic number, e.g. compare NH_4^+ and OH_3^+; $R_3N:O$ and $R_2O:O$ and $RI:O$ ($RCl:O$ not known); also $N(Me)_4I$, and $S(Me)_3I$ and IPh_2I.

Quantum conceptions require that in the so-called unshared state these electrons are contributing to the linkages between, for example, the nitrogen and the three groups R in $:NR_3$. The above chemical requirements do not conflict with this. The chemist is primarily interested in how these electrons can become available for forming new linkages and he only becomes involved in a consideration of how they are behaving in the "unshared" state in a few cases. One of the most important of these arises from the consideration that these electrons will contribute to the effect of the nitrogen on the static or statistical properties of the groups R in NR_3, and, if these groups are not all the same, the contribution of these electrons will not be symmetrical. Also, "unshared" electrons will more easily assume unsymmetrical distributions than the more definitely restrained electrons of an atom in which all the electrons are already shared in single bonds (e.g. in CR_4). This is closely related to the ideas which have been advanced in this country concerning the initiation of alternation in the properties of carbon atoms in conjugated systems of various types (compare Robinson [4]).

These ideas have been based on a variety of conceptions each associated with a different name. These include conceptions relative to effects known as quantitative,[1] conjugative,[2] tautomeric,[3] electromeric,[4] and primary interior.[5] These terms are not all synonymous e.g. "primary interior effect" strictly applies only to the static or average molecule of a substituted compound in given circumstances, whilst tautomeric and electromeric effects include also conditions of the molecule widely removed from the average. The most important and extensive application of these ideas has

[1] Flürscheim, *J.C.S.*, 1909, **95**, 918.

[2] Allan, Oxford, Robinson and Smith, *J.C.S.*, 1926, 402.

[3] Ingold, Annual Reports, 1926-28; *Recueil Trav. Chim.*, 1929, **48**, 802.

[4] Robinson, "Outline of an Electrochemical Theory of the Course of Organic Reactions," Institute of Chemistry, 1932.

[5] Lapworth and Manske, *J.C.S.*, 1928, 2533.

been their use in the interpretation, in one coherent scheme, of the following properties of benzenoid compounds: (*a*) substitution in benzene derivatives, (*b*) the dissociation constants of substituted benzoic acids, phenols, amines and cyanohydrins,[1] (*c*) the rates of reactions involving groups attached to benzene. It is perhaps necessary to emphasise that the organic chemist is justified in attempting to account for these apparently unrelated properties in terms of structural and valency (i.e. electronic) relationships by the remarkable degree of parallelism between the effect of a given substituent on one of these properties and its effect on the other two, which has been found to obtain with a very wide range of substances and phenomena.

The view that these "unshared" electrons, when present on an atom next to the benzene nucleus, have a predominating influence in leading to *o*- and *p*-substitution is supported by the general parallelism which exists between the basic or co-ordinating properties of the "unshared" electrons of atoms attached to benzene and the directive power, in aromatic substitution, of groups containing such atoms, e.g. in the series

$$—O^-,\ —NMe_2,\ —OMe,\ —NH\,.\,CO\,.\,CH_3,\ \text{halogen},$$

the *o*-*p*-directive power decreases from left to right together with the related phenomena, and so does the basicity and co-ordinating power of the atom attached to benzene. Also, in the series —F, —OMe, —NMe_2, —CMe_3 the directive power increases rapidly from —F to —NMe_2 and then falls to a minimum value for —CMe_3 which carries no unshared electrons.

It is significant that the dipole associated with the group shows no such parallelism to directive power, e.g. amino derivatives and methyl show a positive dipole

$$\left(\gt\overset{-}{C}—\overset{+}{C}H_3\right) \qquad \text{(B)}$$

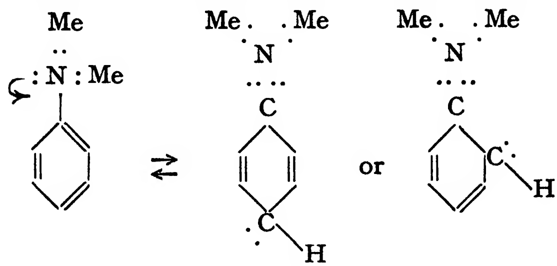
and —OMe and halogens show negative dipoles like the *m*-directive groups. Sutton[2] has shown that the displacement of the electronic "centre of gravity" in the benzene nucleus, which arises from the introduction of a substituent,

[1] Lapworth and Robinson, *Nature*, 1932, **130**, 273.
[2] *Proc. Roy. Soc.*, 1931, A, 133, 668.

does not follow the dipole effect but corresponds to electron repulsion when the group is *o-p*-directive.

The interpretation of the genesis of *o-p*-directing power on the basis of these considerations has taken several forms. The following is a summary of some of the essential features of these and indicates some of the main issues involved.

By the element next to the nucleus using its unshared electrons to increase its covalency with the first carbon atom, the molecule can change over into a quinonoid form :

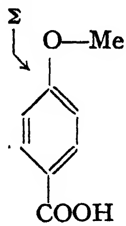


. (C)

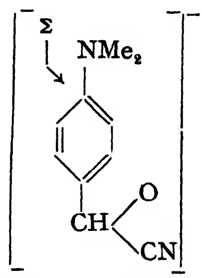
It is not possible to formulate any analogous change which gives rise to unshared electrons on the *m*-carbon atom without associating more than eight electrons with at least one carbon atom, and *m*-quinonoid forms are not known. The disposition to change to the *o*- and *p*-quinonoid forms would follow the series of groups given above and, further, the most powerful *o*- and *p*-directive groups are those which do give rise to quinonoid structures when the *o*- or *p*-position carries a group which can absorb the unshared electrons in that position (compare triphenylmethane, example A, p. 38). Hence it is argued that when a substituting agent (in all ordinary cases an oxidising agent, i.e. an electron acceptor) attacks the *o*- and *p*-positions the electrons can become available for uniting it through a change to (*or towards*) the quinonoid form. This process was generally regarded as arising almost entirely at the demand of the reagent in this way, and this would account for the velocity phenomena both in substitution reactions and replacements, in nearly all cases, because these are not necessarily regulated by conditions in the " average molecule."

However, for example, *p*-methoxybenzoic acid is a weaker acid than benzoic in spite of a (dipole) field effect which should

make it stronger; and *p*-dimethylaminobenzaldehyde cyanohydrin is much more highly dissociated than the *m*-isomeride. These are typical equilibrium phenomena and indicate statistically permanent conditions of the molecules or ions or both, which are interpreted by considering that the groups —OMe and —NMe_2 produce statistically permanent electron pressure at the first carbon atom which in turn gives rise to electron pressure in the *p*-position.[1]

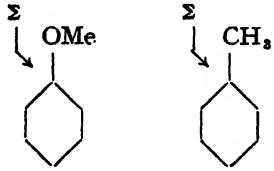


High electron pressure at C_p, more restraint on H^+.

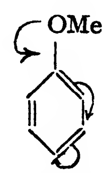


High electron pressure at C_p, less restraint on CN′.

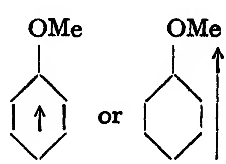
[1] Once this is postulated it confuses the conception of an inductive effect which is transmitted by electronic mechanisms, and it appears to be necessary to regard this as essentially transmitted externally, i.e. as a field effect (Cocker and Lapworth, *J.C.S.*, 1930, 440). On this basis the main effects produced by the introduction of a substituent into a molecule are to be divided into (*a*) primary effects which we are discussing, (*b*) effects which can arise in the course of a reaction when complete covalency changes are possible, and (*c*) field effects. We suggest that the first arises mainly from the fact that the substituents are composed of atoms, the electrons of which are subject to quantum laws, and the last from the charges (dipole or ionic) which are associated with nearly all substituents. It appears that Hückel in his quantum treatment of this problem (*Zeit. fur Physik*, 1931, **72**, 310) made an initial error in starting from the dipole instead of from considerations of the atomic nature of the substituents (compare B, p. 40). The symbols used for these various effects apply unaltered:



Primary effect



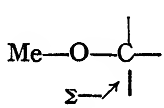
Electromeric effect.



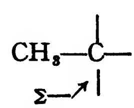
Field effect.

Also the displacement of the " electronic centre of gravity " away from *o-p*-directive substituents which Sutton (*loc. cit.*) deduces from dipole measurements is a feature of the average molecule. It is therefore clear that there are permanent electronic displacements in the aromatic nucleus of the average molecule which correspond generally both in direction and intensity with the electromeric effects deduced from experiments on substitution and other reaction velocity phenomena.

It is generally agreed that this primary effect cannot arise from the presence of a greater amount of the quinonoid form in the equilibrium (C, p. 41), and this permanent electron repulsive effect of groups like —OMe cannot therefore be due to a full electromeric change. The question therefore remains as to what is the nature of this electron pressure, and particularly in what respects it differs from the electron repulsive effect of —CH_3. This group is also definitely *o-p*-directive and influences dissociation constants and the properties of other groups in a way similar to other *o-p*-directive substituents although it has no " unshared " electrons. Lapworth regards the difference as essentially one of degree and not of kind, and in all cases, whether the *o-p*-directive substituent is attached to saturated or unsaturated carbon, he writes the effect as :



or



He has pointed out that the electron release produced by methyl will arise not only from the dipole effect but from other factors as well, and particularly that whereas in *C*—H the hydrogen is able to contribute most effectively to the restraint of the electrons, being embedded in the structure of the carbon atom, in *C*—CH_3 this no longer applies and electron release is favoured.

We regard as specially significant the *o-p*-directive power of —CH_2Cl, which has a negative dipole and increases the dissociation constants of acids into which it is introduced (H . COOH $K_{25^\circ} = 2{\cdot}1 \, . \, 10^{-4}$; Cl . CH_2 . COOH $K_{25^\circ} = 1{\cdot}52 \, . \, 10^{-3}$; H . CH_2 . COOH $K_{25^\circ} = 1{\cdot}8 \, . \, 10^{-5}$; Cl . CH_2 .

$CH_2 . COOH$ $K_{25°} = 8·4 . 10^{-5}$). The inductive effect of $—CH_2Cl$ is therefore clearly electron attractive, yet when this group is directly attached to the aromatic nucleus it is *o-p*-directive. Using Lapworth's conceptions, or the interpretation developed in this paper, no special mechanism, such as that suggested by Ingold (*Rec. Trav. Chem.*, 1929, **48,** 804) is required to accommodate these facts.

It is necessary to consider a little further certain features of the newer views of molecular structure in order to indicate more fully how they may reconcile many of the organic requirements in a way which was not possible on the Lewis-Langmuir conception which has generally provided the background for organic chemical discussions.

It has been customary to regard molecules as made up of atoms which retain their identity in the molecular structure. On the quantum view the completed molecules must be regarded as deviating more or less from this state towards what has been called a condensed atom, in which the atoms making up the molecule have lost their identity and the new molecule tends to simulate an atom built up from the original atoms. For simple molecules Mulliken[1] considers that ". . . no attempt is made to treat the molecule as *consisting* of atoms or ions. Attempts to regard a molecule as consisting of specific atomic or ionic units held together by discrete numbers of bonding electrons or electron pairs are considered more or less meaningless except as an approximation in special cases."

The molecule is considered rather as a set of nuclei to which the appropriate number of electrons are added; as the electrons are added to such a nuclear configuration they will fall into their lowest possible energy levels, some of which may be associated with the nuclei and others with the molecule as a whole, so building up a set of molecular electronic levels.

In the extreme case when the two nuclei of the original atoms are welded together into a new nucleus, the electrons which were originally associated with the separate nuclei

[1] Mulliken, *Phys. Rev.*, **40,** 55 (1932); *Chem. Rev.*, **9,** 347 (1931); *Rev. Mod. Phys.*, **4.**

will now occupy new atomic levels. This will involve the promotion of electrons from low energy levels to higher ones. Molecule formation *in simple cases* (e.g. CH) tends to this extreme state of affairs, and although the tightly bound electrons such as (1*s*) remain attached to the separate nuclei the rest of the electrons are involved in the new molecular energy levels, a process which will in most cases involve the promotion of some of the electrons. The process of promotion would only be complete when the new atom had been formed, but the molecule tends to this state.

In this case the electrons can be divided into three classes, (*a*) bonding, (*b*) antibonding, (*c*) non-bonding. In molecules (free radicals) of the type CH and OH it is probable that apart from the (1*s*) electrons of the carbon or the oxygen, the electrons are not associated with the two nuclei but occupy molecular levels. As the atoms become more complex there is a tendency for the inner shells of electrons to remain associated with the nuclei, while the outer electronic shells become thoroughly shared and "molecular."

As we pass to more complex or to less stable molecules formed from atoms with larger numbers of electrons in their outer shells, the sharing of these shells is less complete and the molecule may be considered to consist of separate atoms. For example, Mulliken points out that as we pass from N_2 to F_2 the number of antibonding electrons increases, the size of the 2*s* and 2*p* "orbits" decreases on account of the increase in nuclear charge, and the equilibrium distance between the two nuclei increases.

$$N\ (1s)^2\ (2s)^2\ 2p\ 2p\ 2p \qquad N_2\ (1s)^2\ (1s)^2\ (\sigma 2s)^2\ (\sigma^*\ 2s)^2\ (\pi 2p)^4\ (\sigma 2p)^2$$
$$F\ (1s)^2\ (2s)^2\ (2p)^2\ (2p)^2\ 2p \qquad F_2\ (1s)^2\ (1s)^2\ (2s)^2\ (2s)^2\ (\sigma 2p)^2\ (\pi 2p)^4\ (\pi^*\ 2p)^4$$

In N_2 the ($\sigma 2s$) and (σ^* 2*s*) electrons (which are probably associated with the molecule as a whole and are exercising strong bonding and antibonding effects), probably do not exist in such levels in the case of F_2, but such electrons may in this case belong to the separate nuclei as (2*s*) electrons.

In discussing the groups which are effective in bringing

* Indicates antibonding.

about *o-p*-substitution in benzene, the following is the accepted order of decreasing effectiveness:

—O′ —NH_2 —NMe_2 —OH —OMe Halogen —CH_3

Following the condensed atom conception we can, in the case of the hydrogen compounds, consider the groups —NH_2 —OH —CH_3 as new atoms made up from the constituent atoms. The same method has been adopted with compounds of the type of C_2H_4 and B_2H_6, considering such molecules to be built up from atomic groups CH_2 and BH_3 which in the condensed form will resemble oxygen.

The assumption made here is that the electrons originally belonging to the hydrogen have now become part of the electronic system of the whole group. When such a group enters into combination it will employ the outer electrons whether or not the electrons originally belonged to the hydrogens. Using this scheme we can write the electronic structures for these *o-p*-directing groups as follows:[1]

$$
\begin{array}{rl}
—\mathrm{O}' & (1s)^2\ (2s)^2\ (2p)^2\ (2p)^2\ 2p \\
—\mathrm{NH_2} & (1s)^2\ (a2s)^2\ (a2p)^2\ (b2p)^2\ c2p \\
—\mathrm{OH} & (1s)^2\ (a2s)^2\ (a2p)^2\ (b2p)^2\ c2p \\
—\mathrm{F} & (1s)^2\ (2s)^2\ (2p)^2\ (2p)^2\ 2p \\
—\mathrm{CH_3} & (1s)^2\ (a2s)^2\ (a2p)^2\ (b2p)^2\ c2p.
\end{array}
$$

All the groups simulate the fluorine structure and their influence on electronic availability on adjacent atoms will be of the same kind, but the differences which exist between the various groups in *o-p*-directing power will arise because the groups are not completely condensed atoms and will therefore not exactly imitate the halogens, and from this point of view it is possible to discuss the differences which will be manifested between these various groups. For example, in —NH_2 and —OH the fact that the groups are not in the full "condensed atom" state will impose the restrictions of an unsymmetrical field on the movements of the electrons so that to some extent the availability of electrons in these groups will be

[1] The letters *a*, *b* and *c* are merely used to distinguish different kinds of *s* and *p* electrons and have no physical significance.

governed by the availability of the electrons in the simple nitrogen and oxygen atoms. The availability of electrons decreases as we pass from nitrogen to fluorine, and when these atoms enter into combination the bonding becomes less of the condensed type as we pass towards the halogens. Electrons of the (2*s*) type, which include the so-called "unshared" pair, take less and less part in the bonding, and the number of highly promoted electrons, whose influence is an antibonding one, increases. This means that there will be more electrons contributing to the bonding in the case of nitrogen than in oxygen, and more in oxygen than in the halogens.

We should expect therefore, to find a gradual decrease in any effects which are dependent upon the availability of electrons, or on the number of electrons contributing to a bond as we pass from nitrogen to the halogens, and in so far as the *o-p*-directing power is dependent upon the contribution of electrons from the substituent group to the bond attaching such groups to the benzene nucleus we should expect a parallel decrease in *o-p*-orienting power. This would correspond to the fractional "increase of covalency" which seems to be required by the organic data, but there are advantages in restricting the term "increase of covalency" to changes of whole units of covalency such as take place in the formation of quinonoid forms and which are of a discontinuous type involving an "electron switch" in contrast to the above effects which may be considered to vary continuously as the groups are brought together. It does not appear to be possible at present to decide how great a part is played in orientation and other velocity phenomena by true electromeric effects, on the one hand, and by statistically permanent effects such as are discussed above on the other, but we suggest that influences of the latter type will prove to be more important than they have generally been considered to be.

Special Cases.

—*CH_3 group.*—As far as the effect which we are considering is concerned, this group falls into line with the other *o-p*-directing groups, since as a condensed atom group it

simulates the structure of the halogens, and all the electrons (except the $1s$ electrons of the carbon) are making up the outer electronic shell of the group. The methyl group cannot, of course, take part in full electromeric change to quinonoid forms.

—NH_2 and —OH groups.—In the simpler case of NH_3 the three hydrogen nuclei are 'embedded' in the new molecular wave-functions:

$$\begin{array}{ll} \mathrm{N} & (1s)^2\ (2s)^2\ 2p\ 2p\ 2p \\ \mathrm{NH_3} & (1s)^2\ (\sigma 2s)^2\ (\sigma 2p)^2\ (\pi 2p)^2\ (\pi 2p)^2. \end{array}$$

The hydrogen nuclei will be chiefly concerned with the four $\pi 2p$ and to a lesser extent with the $2s$ wave functions. The $2p\sigma$ electrons in NH_3 will tend to avoid the hydrogen regions although they are occupying the new molecular levels. These electrons will be *relatively* loosely bound. If we replace one of the hydrogens in NH_3 by a large group such as benzene we may have the stabilisation of the two loosely bound $2p\sigma$ electrons by the proximity of a large nucleus. This stabilisation will not generally be as complete as it is when these $2p\sigma$ electrons are stabilised by the addition of an extra nucleus such as the H ion, but we can conceive of a half-way effect in which the relatively loosely bound $2p\sigma$ electrons are brought into the linkage by the stabilising influence of the benzene nucleus. Such an effect shows itself in the decreased basicity of $Ph . NH_2$ as compared with $CH_3 . NH_2$ and $H . NH_2$ and the increased acidity of Ph . OH compared with methyl alcohol and water.

Ionisation Potentials.—More definite evidence would be forthcoming from the ionisation potentials for the various electrons concerned in these linkages. The loose binding of the $2p\sigma$ electrons in NH_3 is shown in the low ionisation potential of this molecule, 11·1 volts as compared with 14·5 volts for CH_4. Similarly for H_2O the ionisation potentials for the various electrons may be given as

$2pc$ ("lone electrons") 13·2 v; $2pb$ 16 v; $2pc$ 17 v; $2s$ 30 v.

We should expect an increased ionisation potential in the case of $Ph . NH_2$ and Ph . OH for the $2p\sigma$ and $2pc$ electrons

owing to the semi-stabilisation we have postulated. In this connection the work of Klingstedt on the energies of excitation as determined from the ultra-violet absorption spectra for Ph . CH_3, Ph . NH_2, Ph . OH, and Ph . F is particularly interesting. If the state of affairs we have postulated holds, we should expect that the more intimately the so-called "lone electrons" are involved in the binding the greater would be the energy of excitation as Klingstedt found.[1] The table below, taken from his paper, summarises his results, the energies of excitation being taken with reference to benzene as zero.

	$C_6H_5 . CH_3$	$C_6H_5 . NH_2$	$C_6H_5 . OH$	$C_6H_5 . F$	C_6H_6
ΔE cals./mol.	177	8900	3200	1050	0

It is important to realise that the above discussion is confined to the bond between the directing group and the benzene nucleus or other hydrocarbon structure, and it is not possible to decide from theoretical considerations what definite influence such changes of binding will have on other positions in the attached molecular structure. Also it is only possible to indicate generally what effect substituents in the directing group will have on the binding. We have considered groups such as —OH and —NH_2 as condensed atoms possessing electrons available for binding irrespective of the original attachment of such electrons. If groups other than hydrogen are attached to the oxygen or nitrogen then the more such atoms or groups are able to retain their identity the greater will be the deviation in behaviour from the condensed atom form. This deviation will have two results :—

(*a*) The groups attached to the nitrogen or oxygen will no longer be part of the condensed atom, and so the effective "nuclear charge" of the atomic system attached to the benzene nucleus will be virtually reduced.

(*b*) There will be a more specific attachment between electrons and substituent groups giving rise to a state of affairs which can be represented by directional valencies.

[1] Klingstedt, *Zeit. f. Phys. Chem.*, Abt. B., **20,** 125 (1933).

Such effects as these will profoundly influence the nature of the binding of these groups to the nucleus. The replacement of the hydrogen in $—CH_3$ by other groups not only reduces the nuclear charge by destroying the condensed atom system but also removes to some extent the electrons which were available and taking part in the bond when the group resembled the fluorine structure. Such a decrease in availability of electrons may contribute to the apparent decrease in *o*-*p*-directing power of substituted methyl groups (compare Le Fevre, *Nature*, 1933, **131,** 655, on the relative effects of methyl and *tert*-butyl).

The authors wish to acknowledge their indebtedness to Professor Lapworth for his interest in this discussion.

V.—A Redescription of the known British Silurian Species of *Calymene* (s.l.).

By J. Shirley, M.Sc.

Received for publication, May, 1933.

Introduction.

The present paper is a continuation of the work already published upon the British Ordovician species of *Calymene* (Shirley, 1931). From British Silurian rocks there have been described four species or varieties of trilobites belonging to this genus, including the genotype. These will be redescribed and refigured. The problems of nomenclature will be studied and, it is hoped, finally solved. In a future paper it is proposed to give an account of new species belonging to this group and to discuss their relations with one another. For the terminology used in describing these trilobites reference should be made to the previous paper. All measurements are given in millimetres.

Acknowledgments.

My best thanks are due to Dr. F. L. Kitchin of the Geological Survey and Museum, Mr. A. G. Brighton of the Sedgwick Museum, and Mr. T. H. Withers of the British Museum, for allowing access to the collections under their care and for help whilst working through them. I have also to thank Professor Jacob of the Sorbonne, Paris, Miss Elsa Warburg of the Riksmuseum, Stockholm, and Dr. J. P. J. Ravn of Copenhagen, who allowed me the great privilege of studying type material preserved in the various institutions. To Professor O. T. Jones, who helped me in the earlier stages of the work, and to Mr. S. H. Straw and Dr. Stubblefield who

have given much helpful advice and encouragement, I express my grateful thanks. The work has been completed in the Geological Department of Sheffield University and the laboratories of the Fuel Research Board and I am indebted to Professor W. G. Fearnsides and Dr. L. Slater for the facilities provided.

NOMENCLATURE.

Research into the history of the names of Silurian species of *Calymene* has revealed problems of some complexity. The main one is concerned with the name of the genotype: whether it shall be *C. blumenbachi* Brongniart (1822, p. 11) or *C. tuberculata* (Brünnich, 1781, p. 389). On the grounds that Brünnich's name preceded that of Brongniart, Lindström (1885, p. 63) allowed *C. blumenbachi* to fall. Continental authors generally have followed Lindström's lead in naming specimens of this type and have regarded the matter as finally settled. But English and American authors have continued to use the name *C. blumenbachi.* So far as is known, nobody has considered the existence of type specimens.

Brünnich described four specimens as "*Trilobus tuberculatus*" and these are preserved in the collections of the University of Copenhagen. The first shows a cranidium more than half buried in matrix and six attached thoracic segments. It is impossible to refer the specimen to any of the species recognised as occurring at Dudley, the type locality. The second shows twelve thoracic segments and an attached pygidium; in the absence of the cephalon it cannot be identified with certainty. The third is a small piece of shale labelled as coming from the River Onny, Shropshire, upon which is a pygidium of an undescribed species of *Calymene* associated with fragments of *Trinucleus* sp. The fourth specimen is an almost complete *Asaphus* preserved in a dark blue crinoidal limestone. Dr. C. J. Stubblefield, to whom this specimen was referred, states that it is a true *Asaphus*, probably *A. expansus* (Linnæus) which occurs in the *Expansus* shales and limestones of Scandinavia and the eastern Baltic. It is not known to occur in Britain.

Disregarding Brünnich's name, Brongniart referred to

the "Dudley Trilobite" as *Calymene blumenbachi*, illustrating two specimens. In the collection of the Sorbonne, Paris, are specimens which belonged to Brongniart and which formed the basis for the figures. These are two, one enrolled and one extended but incomplete; a third specimen which probably also belonged to Brongniart, but was acquired by the Sorbonne at a later date, will be left out of account because of the uncertainty regarding its history. The enrolled specimen will be regarded as the type of *C. blumenbachi*: it evidently formed the basis for Fig. 1*a*, *b*, Pl. I, of Brongniart's work. It is fairly well preserved and can be identified with certainty with other specimens occurring at Dudley.

On the grounds, therefore, of inadequate description and types, the name *tuberculata* for any species of *Calymene* must be allowed to fall. And, since *Calymene blumenbachi* can be identified with certainty, the name stands, and further, since it is the first-mentioned species in Brongniart's genus it is regarded as the genotype.

The other problem of nomenclature concerning the Silurian Calymenidæ is comparatively simple. As already pointed out by Lindström (1885, p. 66) *C. tuberculosa* of Salter (1848, p. 342) is not identical with *C. tuberculosa* of Dalman (1826, p. 227) and a new name must be found for Salter's species. The name *Calymene nodulosa* is proposed.

Calymene nodulosa nom. nov.

(Pl. I, Figs. 6-11.)

Calymene blumenbachi, Murchison (Sir R. I.), 1839. *Silurian System*, Pt. II, Pl. VII, Fig. 5.

Calymene tuberculosa, Salter (J. W.), 1848. Palæontological Appendix (in *Mem. Geol. Survey Great Britain*, Vol. 2, Pt. I), p. 342, Pl. XII, Figs. 1-3, 5.

Calymene tuberculosa, Salter (J. W.), 1849. *Mem. Geol. Survey Great Britain.* Decade I, Pl. VIII (not Figs. 6 and 8).

Calymene tuberculosa, Salter (J. W.), 1865. "Monograph of the British Trilobites" (Palæontographical Society), pp. 91-92, Pl. VIII, Figs. 1-6.

Most of the published figures are restorations but nevertheless give a good idea of the characters of the species. Of those figured in the Memoir of the Geological Survey, Pl. XII, the original of Fig. 1 (Survey Museum 19642), is the best preserved and is here chosen as the type. Certain features are not displayed by this specimen and these are described from Survey Museum specimens 19644 and 19646.

The trilobite, as a whole, has a flattened appearance due to the relatively broad thorax and to the width of the pleuræ between the axis and the turndown. The animal seems to be rarely enrolled, usually exhibiting a "sway back" outline.

The cephalon is broad, subtriangular, with a protruding preglabellar field. The glabella is a little shorter than the fixed cheeks with a triangular outline rounded in front. The occipital ring is longer in the middle than at the sides, where there is a rounded tubercle similar to those on the segments of the axis of the thorax. The occipital ring is shallow in the median portion and deep behind the first lobes. The glabellar lobes are evenly graduated in size. The first lobes are large, subquadrangular, but appear rounded when viewed from above. The first grooves are deep, bifurcate with small intermediate lobes. The second lobes are rounded, with papillate extensions to the buttresses on the fixed cheeks and separated from the median portion of the glabella by lobe grooves. The second grooves are bifurcate without intermediate lobes. The third lobes are small, distinct and slightly raised from the transverse outline of the glabella but without showing definite lobe grooves. The third grooves are distinct. "Supplementary" grooves have not been seen on these specimens, but an internal cast, Survey Museum 6588, which is the specimen figured by Murchison, shows a groove on the right side of the glabella ascending from the "antennary" pit. The frontal lobe has a semi-elliptical outline and descends to the preglabellar field without overhang. The preglabellar field is very long and spoon shaped, and is turned up higher than the glabella; there is a slight indication of "thickening."

The axial furrows are deep, somewhat sigmoid in curvature

contracting to nothing at the point where the second lobe is in contact with the buttress on the fixed cheek. The antennary pits are very well shown. They are not situated directly on the floor of the axial furrows but on the sides towards the glabella.

The fixed cheeks are convex, and when viewed in profile the posterior part of the glabella stands well above the contiguous part of the fixed cheeks, whereas the frontal lobe is but slightly above the level of the fixed cheek about the eye.

The anterior portion of the fixed cheek falls almost vertically into the intramarginal furrow; the posterior intramarginal furrows are relatively deep in this species. The eyes are situated opposite the second glabella lobes. The facial sutures are not well shown by any of the above-mentioned specimens. The free cheeks are also damaged. They stand almost vertical, being turned slightly inward underneath the cephalon, and the rim is deflected strongly outward.

The thorax of thirteen segments has a broad, flattened appearance due to the wide horizontal portion of the pleuræ. On each side the axial rings have a prominent knob which is covered by a coarser ornament than the rest of the test. These knobs are more pronounced on the internal cast.

The pygidium is convex and has a drawn-bow shape. The axis, shorter than the pygidium, has one indistinct and six distinct rings each of which shows a small knob on each side corresponding to those on the thoracic rings. The pleural portions have four ribs each very faintly divided. At about a third of their length from the edge of the pygidium they disappear, leaving a smooth border.

The ornament is well preserved on the type specimen. On the median portion of the glabella it consists of small, but fairly even-sized, hemispherical tubercles. On the cheeks the ornament is similar, but on both portions of the cephalon towards the axial furrows and particularly on the second lobes and the buttresses, the tubercles become much larger. This change in coarseness of the ornament towards the axial furrows can also be observed on the thorax and pygidium.

Localities:

Burrington, near Ludlow, Shropshire: Old quarry at the side of Nant Tresglen behind Half-Way Inn, five miles east of Llandovery.

Horizon:

Wenlock.

Remarks:

The features which distinguish *C. nodulosa* from other Silurian species are, the relatively short, triangular glabella with its peculiar attitude relative to the fixed cheeks, the unusually long preglabellar field, and the characters of the pygidium. The development of knobs on the axial rings is shown to a less extent by *C. allportiana* which also shows a similar but finer grained ornament. Otherwise, so far as is known, the ornament of *C. nodulosa* is peculiar and, when preserved, serves at once to distinguish the species. All the specimens in the Survey Museum which have been examined were found in the Wenlock shale of Burrington, Shropshire, but Mr. S. H. Straw has found specimens preserved as casts at the other locality given above, associated with a Wenlock fauna.

Measurements of specimen 19642 Survey Museum:

Glabella:			
Length			12·0
Breadth across the first lobes			10·5
Breadth of the frontal lobe			5·75
Pygidium:			
Length			12·25
Breadth			22·5
Axis Length	10·5	Breadth anterior	7·0

Calymene allportiana SALTER, 1865.

(Pl. I, Figs. 12-14.)

Salter (J. W.), 1865. "Monograph of the British Trilobites" (Palæontographical Society), p. 95, text Fig. 20.

This species, of which only one specimen has been seen, was first noticed by Salter under the name *C. blumenbachi* var. *allportiana.* Since that date it seems to have been lost sight of but the specimen figured by Salter has been rediscovered in the Allport collection in the British Museum (Specimen 58984). It is proposed to raise the variety to the rank of a species.

The specimen consists of an extended individual with the sway back outline shown by *C. nodulosa.* It is almost complete and the test is preserved.

The cephalon is subtriangular in outline with a tendency to a nasute appearance caused by the forward projection of the preglabellar field.

The glabella narrows gently forward and is rounded in front, where it reaches further forward than the fixed cheeks. The neck ring has been damaged, but on the right side the large axial knob is shown. There are three lobes on each side similar to those of *C. nodulosa* except that the first pair do not project so far beyond the second. There are distinct intermediate lobes between the first and second lobes on each side. The frontal lobe is semi-elliptical in outline and rises steeply from the preglabellar field. The median portion of the glabella is convex and stands a little above the lateral lobes.

The axial furrows are obscured by matrix but are contracted at the second lobes where there is a buttress on the fixed cheeks.

The preglabellar field is similar to that of *C. nodulosa* in being upturned, nasute and but very slightly thickened, but differs in being a little shorter.

The eyes are placed opposite the second glabellar lobes. The anterior portions of the fixed cheeks fall almost vertically forward into the intramarginal furrow. The free cheeks turn vertically downward from the eyes, and their intramarginal furrows are broader and shallower than those of *C. blumenbachi.*

The thorax of thirteen segments is convex and tapers gently backward. The axis has a semi-elliptical cross-section and each segment has a strong knob on each side just

above the axial grooves. The pleural fulcra are relatively less distant than in *C. nodulosa*, and beyond them the pleuræ turn strongly but evenly downward through nearly a right angle.

The pygidium is bent down at right angles to the contiguous portion of the thorax and has been rather roughly dealt with in cleaning away the matrix. Its axis is broader and less convex than that of *C. blumenbachi*, and shows six rings. The pleural portions have four ribs on each side, each faintly grooved up to about half-way from the border.

The ornament of the test is shown clearly only on the cephalon. The median portion of the glabella is ornamented with tubercles of two main sizes, each smaller and set more closely than in *C. blumenbachi*. Compared with the corresponding ornament in *C. nodulosa*, the tubercles are larger but much more closely set. On the cheeks the ornament is of similar character, but finer grained except along the axial furrow where it becomes coarse and relatively large papillate tubercles are developed. This change of the ornament on approaching the axial furrows of the cephalon is observed in *C. nodulosa*, but only to a very slight extent in *C. blumenbachi*. The ornament of the thorax and pygidium is not shown, the surface apparently having been cleaned with acid.

Horizon and Locality:

"Wenlock" Limestone, Dudley, Worcestershire.

Remarks:

Salter suggested that this species may be intermediate between *C. nodulosa* and *C. blumenbachi*. The connection between *C. nodulosa* and *C. allportiana* is evident when the two forms are compared. The two species differ in those characters which are considered to alter during evolution. *C. allportiana* has a relatively higher glabella whose frontal lobe is wider and rises more steeply from the preglabellar field than the corresponding portion of *C. nodulosa*. The thorax of *C. allportiana* is less wide and more convex than that of *C. nodulosa*. In the pygidium the ribs are grooved in *C. allportiana* but not in *C. nodulosa*.

From *C. blumenbachi*, *C. allportiana* differs in having a

longer and less upturned preglabellar field, a less convex glabella, whose frontal lobe is less truncate and not so swollen, and much stronger knobs on the axis of the thorax. The ornament of *C. allportiana* is finer and set closer than that of *C. blumenbachi*, and, as stated above, the latter does not show the change in ornament on approaching the axial furrows.

On the whole *C. allportiana* is more closely related to *C. nodulosa* than to *C. blumenbachi*. Whilst not denying that *C. allportiana* may have evolved into a form similar to *C. blumenbachi*, the lack of intermediate forms between the two species renders the hypothesis frail.

Measurements :

Cephalon : Length			14·5
Glabella : Length			11·5
Breadth across the first lobes			9·5
Breadth of the frontal lobe			6·5
Pygidium : Length	9·0		
Axis length	7·5	Breadth anterior	6·5

Calymene blumenbachi Brongniart, 1822.

(Pl. I, Figs. 1-5.)

Brongniart (A.). 1822. Histoire naturelle des Crustacés fossiles. P. 11. Pl. I, Figs. 1a, 1b.

The type specimen is enrolled and complete except that the free cheeks are damaged and displaced. The test shows little trace of ornament except on the front portion of the frontal lobe and on the left fixed cheek.

The cephalon is convex and relatively broad ; more complete specimens show a very slight tendency to a triangular outline with the preglabellar field projecting a little.

The glabella is subtrapezoidal in outline. The transverse profile is very convex with the profiles of the lateral lobes projecting from that of the median portion of the glabella. The anterior of the glabella reaches further forward than the fixed cheeks. The occipital ring is longer in the centre than at the sides where the ends are turned slightly forward. The

occipital groove is moderately deep in the median portion where it swings forward and is excavated behind the first lobes. There are three distinct lobes on each side, whilst a fourth is indicated by a slight bulge. The first lobes are large but project little from the general outline. They are subquadrilateral, with anterior and posterior edges diverging outward ; the outer edges are rounded and their inner edges defined by shallow lobe-grooves. The first grooves are deep, directed obliquely inward and backward, and bifurcate. The deeper posterior branches turn inward to invade the median portion of the glabella and are joined by the first lobe-grooves. The second lobes are elongate in the transverse direction when viewed obliquely from the side, but when viewed from above they show a papillate outline as if reaching out to the buttress on the fixed cheeks. The second grooves are deep and their inner ends join the second lobe-grooves. The third lobes are considerably smaller than the second pair and project little from the sides of the frontal lobe. The third grooves are shallow. There is a faint swelling on each side of the glabella in front of the third groove suggesting the presence of fourth lobes. The frontal lobe is swollen, overhanging both the preglabellar field and the axial furrows and, viewed from above, it shows a somewhat rectangular outline.

The axial furrows are contracted at the base, expand round the first lobes, contract at the second lobes, and then run straight forward to join the preglabellar and intramarginal furrows. The "antennary" pits are placed outside the fourth lobes on each side in the axial furrows.

The preglabellar field is turned up at a high angle and its upper edge is angular. It is a little thinner at the centre than at the sides.

On the type the right fixed cheek is somewhat damaged but the left is well preserved. The fixed cheeks are convex ; their anterior portions are narrow and parallel sided and their posterior portions are transversely convex, bending evenly downward to the gênal angles. The posterior intramarginal furrows are broad (in the longitudinal sense) and have steep posterior and more gentle anterior edges.

The palpebral lobes are situated on the highest portion of the fixed cheeks. The middle part of each is opposite the anterior edge of the corresponding second glabellar lobe.

The anterior portions of the facial sutures run almost parallel forward to the rim and, on the underside of the doublure, turn inward to the upper angles of the epistome, where they are joined by the epistomial suture. The posterior portions run outward from the palpebral lobes, bend gently backward, crossing the lateral intramarginal furrows, and then, a short distance anterior to the genal angle, bend sharply backward, turning again outward to the genal angles.

Undamaged specimens which can be referred to this species show that the free cheeks stand almost vertical and have broad intramarginal furrows. Their shape is governed by the course of the sutures and approximates to a right angled triangle, the hypotenuse being the outer edge and the short side the anterior portion of the suture.

The thorax of the type is enrolled and obscured by matrix difficult to remove. There are thirteen segments. The cross-section of the axis is approximately semicircular. The axial knobs are distinct but not prominent. The pleurae run horizontally out from the axis to the fulcra and then bend down strongly but evenly. A groove divides each pleuron into a shorter anterior and a longer (in the longitudinal direction) posterior portion. Because of the enrolled condition of the specimen the outer parts of the grooves are obscured.

The pygidium when held with the axis horizontal is semicircular, the postero-lateral borders being the diameter. As a whole it is moderately convex. The axis tapers evenly backward to a blunt termination just before reaching the end of the pygidium. It has six distinct rings and one more faintly indicated. The pleural portions are evenly convex and have four ribs each deeply grooved in the outer half of their length and faintly in the remainder.

The ornament is shown by the type only on the front of the frontal lobe and on the left fixed cheek. It consists of tubercles of several sizes scattered rather openly, that is, there is a flat space between one tubercle and the next.

Horizon:

"Wenlock" Limestone.

Locality:

Dudley, Worcestershire.

Remarks:

A certain amount of variation has been observed in this species. Certain specimens such as Survey Museum 19668, show a more rounded frontal lobe, slightly more projecting first lobes, and a somewhat thinner edge to the preglabellar field. Further, this specimen, which is beautifully preserved, does not show the outward bend of the sutures at the genal angles, and the ornament is more closely set. This can only be regarded as an extreme of variation of the species since it is connected with the typical form by intermediate specimens.

Most of the identifications of *C. blumenbachi* are to be looked upon with suspicion. In most cases only an examination of the original specimens can settle the point. The specimens figured by Salter in the Monograph (1865, Pl. VIII, Figs. 7-16) either belong to new undescribed species or have not yet been traced and examined. A specimen in the Stockholm Museum (No. Ar 6203) identified as *C. tuberculata* by Lindström, differs in certain details from the typical *C. blumenbachi*. Whether these differences are constant can only be settled by an examination of a larger number of specimens. The specimens figured by Schmidt (1894, Pl. I, Figs. 1-7; 1907, Pl. III, Fig. 1) under the name *C. tuberculata* also appear to differ from *C. blumenbachi* particularly in the character of the preglabellar field, but the originals of these figures have not been examined.

Measurements of the type specimen:

Glabella: Length				15·5
Breadth across the first lobes				14·0
Breadth of the frontal lobe				9·5

Survey Museum 19668.

Cephalon: Length	13·5	Breadth		26·5
Glabella: Length				12·5
Breadth across the first lobes				11·5
Breadth of the frontal lobe				8·0
Pygidium: Length	10·0	Breadth		15·0
Axis length	9·0	Breadth anterior		6·0

Calymene papillata var. *puellaris* Reed, 1921.

(Pl. I, Fig. 15.)

Reed (F. R. C.), 1921. "Description of two Trilobites" (in Gardiner (C. I.), "The Silurian Rocks of May Hill"). *Proc. Cotteswold Naturalist's Field Club*, Vol. 20, pp. 221-222.

The type and only known specimen is preserved as an internal cast on a small slab of decalcified sandstone associated with *Wilsonia wilsoni*, *Rhynchonella nucula* and *Beyrichia* sp. It is in the Sedgwick Museum, Cambridge, specimen A3320.

The cephalon is considerably damaged: the upper parts of both cheeks are broken away, obscuring the relationship between the second glabellar lobes and the fixed cheeks. Only the left side of the glabella is preserved, the rest being broken away, showing part of a cast of the hypostome.

The thorax is composed of thirteen segments, not twelve, as stated by Reed. The pygidium is partially turned underneath and consequently obscured. The thorax and pygidium are essentially *Calymene*-like and apparently show no special features.

On the evidence of the characters shown by the cephalon this specimen cannot be referred to *Calymene papillata* Lindström (1885, pp. 73-74. Text-fig.), the holotype of which I have had the privilege of examining. The reasons for this statement are:

The first and second glabellar lobes are separated by a groove of normal width, whereas this groove is very narrow in *C. papillata*.

Although the second lobe is papillate in the internal cast this does not mean that the specimen is related to *C. papillata*, since nearly all Silurian species show this feature, often also externally.

The third and frontal lobes are not produced into a papillate shape as in *C. papillata*.

The axial furrow is broad: it is narrower than usual in *C. papillata*.

The anterior portion of the fixed cheek does not overhang the axial furrows opposite the third and frontal lobes as in *C. papillata.*

The preglabellar field is long and gently upturned (in the original state it would be slightly more upturned). In *C. papillata* it is very steeply upturned, standing vertical.

Comparison of the specimen with the figured specimens of *Calymene intermedia* Lindström (1885, pp. 71-72, Pl. XV, Figs. 5-12) shows considerable resemblances.

The glabella has the parallel sided appearance characteristic of that of *C. intermedia* and the first and second lobes have about the same relative size and the same relations with the axial grooves.

The frontal lobe overhangs the preglabellar field and the axial furrows at the sides.

The preglabellar field is long and moderately upturned.

On the fixed cheeks the eyes have about the same position and the anterior portions fall evenly into the intramarginal furrows.

It is impossible to compare other features, but the similarities already noticed show that the specimen called *puellaris* should be placed with or near to *C. intermedia.* It is, however, so damaged that exact determination is not possible and there is certainly no justification for raising a new species or variety.

The above opinion is strengthened by two other specimens in the Sedgwick Museum. They are not well preserved but they show a sufficient number of characters to place them with *Calymene intermedia.* They are A3319 from the Aymestry Limestone, Whitcliffe Wood, near Ludlow, and A3318 from the base of the Kirkby Moor Flags, three-quarters of a mile south-east of Burnside, near Kendal.

Calymene intermedia has already been recorded as occurring in British Silurian rocks (Reed, 1917, pp. 168-169, and Gardiner, 1921, p. 207), but none of the specimens so identified has been examined by the present author.

Calymene subdiademata McCoy, 1852.

McCoy (F.). 1852. " British Palæozoic Fossils " (in Sedgwick and McCoy), pp. 166-167, Pl. I-F, Figs. 9-10.

On Tablet 137 of the Sedgwick Museum collection are two specimens, one of which is marked as being possibly that represented by McCoy's Figures 10-10*a*. It is an extremely distorted and damaged internal cast of a complete individual. Its appearance is reminiscent of *Calymene quadrata* King and it appears to have only twelve segments in the thorax which further suggests that it may belong to that species. The specimen is too badly damaged to be identified with any certainty. If it is the original of McCoy's drawing, then the drawing is very much restored. The other specimen on the tablet is too flattened to be identified.

The original of McCoy's Figures 9-9*a* cannot be found in the Sedgwick Museum, so that it is impossible to criticise the characters of this species, since it may, like other drawings on the same plate, be represented in a restored condition.

Under these circumstances it seems best to drop the name.

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DESCRIPTION OF THE PLATE.

Calymene blumenbachi Brongniart, 1822.

Fig. 1. Type specimen (× 1⅓), Collection of the Geological Laboratories, Sorbonne, Paris. "Wenlock" Limestone, Dudley, Worcestershire. Figured by Brongniart, 1822, Pl. I, Figs. 1A, 1B.

Fig. 2. The same specimen to show the pygidium (× 1⅓).

Fig. 3. Profile of cephalon of above (× 1⅓).

Fig. 4. Specimen 19668 Survey Museum (× 1⅓). Locality as Fig. 1.

Fig. 5. The same specimen: ornament (×6⅔) of the glabella between the first glabellar grooves.

Calymene nodulosa nom. nov.

Fig. 6. Type specimen (× 1⅓). Survey Museum 19642. Wenlock Shale, Burrington, Shropshire. Figured by Salter, 1848, Pl. XII, Figs. 1, 1*a*; Salter, 1849, Pl. VIII, Figs. 1, 2; Salter, 1865, Pl. VIII, Figs. 2, 3.

Fig. 7. Profile view of above (× 1⅓).

Fig. 8. Cephalon of above (× 1⅓).

Fig. 9. Profile of cephalon of above (× 1⅓). The preglabellar field has been restored from other specimens.

Fig. 10. Part of the glabella and axial furrow of above to show the ornament (× 6).

Fig. 11. Specimen 19646 Survey Museum (× 1⅓). Locality as Fig. 6. Figured by Salter 1865, Pl. VIII, Fig. 5.

Calymene allportiana Salter, 1865.

Fig. 12. Type specimen (× 1⅓). British Museum 58984. "Wenlock" Limestone, Dudley, Worcestershire. Figured by Salter, 1865, text figure, p. 95.

Fig. 13. Profile of cephalon of above (× $1\frac{1}{3}$).
Fig. 14. Part of the glabella of above, including the first, second and third lobes to show the ornament (× $6\frac{2}{3}$). This photograph was obtained through the courtesy of Mr. T. H. Withers of the British Museum.

Calymene, cf. *intermedia* Lindström, 1885.

Fig. 15. Internal cast, figured as *C. papillata* var. *puellaris* by Reed, 1921, p. 222 (× $2\frac{2}{3}$). Sedgwick Museum A3320. Quarry one-third mile E.N.E. of Longhope Church, May Hill.

Calymene intermedia Lindström, 1885.

Fig. 16. Specimen figured by Lindström, 1885, Pl. XV, Fig. 11 (× 2). Stockholm Riksmuseum Ar 6224. Petesvik, Gotland. For comparison with Fig. 15.

PLATE I.

VI.—An Approximate Wave Function for the Normal Helium Atom.

By D. R. HARTREE, PH.D., F.R.S., and A. L. INGMAN, M.Sc.

§ 1. INTRODUCTION.

THE hydrogen atom, and hydrogen-like ions, are the only atomic systems for which the wave equation can be solved exactly; for all others a process of approximation is necessary. Further, in order to compare different approximations, some criterion is necessary to enable us to judge whether one approximation is better than another, although we do not know the actual wave function to which they are approximations.

A method both of finding approximate wave functions and, for the normal state at least, of obtaining a criterion to judge between them, is provided by the variation principle, which states that if for a system whose Hamiltonian function is H, we consider the integral $\int\Psi^*\mathrm{H}\Psi d\tau$ ($d\tau$ being a volume element of the co-ordinate space of the system) evaluated for all functions Ψ subject to the condition $\int\Psi^*\Psi d\tau = 1$, then the functions Ψ for which $\int\Psi^*\mathrm{H}\Psi d\tau$ has stationary values, subject to this condition, are the solutions of the wave equation $\mathrm{H}\Psi = \mathrm{E}\Psi$ for the stationary states, and the stationary values of $\int\Psi^*\mathrm{H}\Psi d\tau$ are the energies of the whole system in the corresponding stationary states.

Further for the normal state the stationary value of $\int\Psi^*\mathrm{H}\Psi d\tau$ is an absolute minimum, so that if one function Ψ gives a smaller value of $\int\Psi^*\mathrm{H}\Psi d\tau$ than another, the smaller value must be nearer the value which would be obtained by using the actual wave function for the normal state, supposing it were known. We can reasonably take this as a criterion for comparing different approximate wave functions, and consider one approximation "better" than

another if it gives a smaller value for the integral. One approximation may, of course, be closer to the actual wave function in one region of co-ordinate space and another in another region, but if a single criterion is required, this is probably the most significant one.

This criterion provides a test of which of two approximate wave functions is the " better." If, further, the energy value for the stationary state is known experimentally, the deviation of $\int \Psi^* H \Psi d\tau$ from this value can be taken as a measure of the " goodness " of the approximate wave function, so that we can speak of one approximate wave function being " twice as good " as another when, for the first deviation of $\int \Psi^* H \Psi d\tau$ from the experimental value is half that for the second. It must be noted here that it is the total energy of the *whole atomic system* which is concerned, not the ionisation energy.

There are two ways of using the variation principle to find approximate wave functions. The first is to consider functions Ψ of specified analytical form containing arbitrary *parameters* which have to be found so as to satisfy the variation principle for functions of this specified form. This process will give not the actual wave function (except in very special cases), but the best approximation to it (in the above sense) obtainable with functions of the form specified. For example, if, r_1, r_2 are the distances of two electrons in a helium atom from the nucleus, we might ask, what is the best approximation to the actual wave function we can obtain with functions of the form $Ae^{-k(r_1+r_2)}$, where A, k are adjustable constants ? We know that no function of this form satisfies the wave equation of the helium atom, so we cannot find the exact wave function in this way, but we can still enquire what is the best approximation to it that we can get with this form of function. This method is an extension of the method of Rayleigh and Ritz, and leads to algebraic or transcendental equations for the various parameters.

The second way is to try a wave function constructed in a specified manner out of arbitrary *functions* of the variables of the problem, these functions being determined so as to satisfy the variation principle. For example we might try a wave function $\psi(r_1)\psi(r_2)$ for the normal helium atom ; again

we know we cannot get an exact solution of this form, but may still ask what is the best solution of this form we can get. This method leads to differential equations for the various functions, and as shown by Slater [1] and Fock,[2] with approximate wave functions of this type, namely, products of functions of the positions of the individual electrons, it leads to the equations of the "self-consistent field" method of treating the many-electron atom, originally suggested by one of us on other grounds [3]; and Fock has shown how this approximation can be improved.

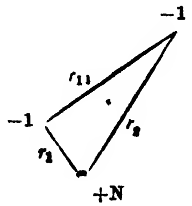
The success of either way of using the variation principle depends on choosing such a form of wave function that with the best values of the parameters (or functions) a fairly good approximation to the actual wave function *can* be obtained; otherwise even the best approximation obtainable with a given form of wave function may not be good enough to be of any value.

The first of these two methods of applying the variation principle has been used by Hylleraas [4] to study the normal state of the neutral helium atom, and of helium-like ions, in some detail, and with great success in that he has obtained an approximate wave function giving a calculated value of the ionisation energy differing from the observed value by less than one part in 3000. The type of wave function used to obtain this result is somewhat elaborate, especially from the point of view of the possibility of extending the calculations to other atoms with more electrons. Hylleraas has also obtained some results with a simpler form of wave function, but, for reasons to be given later (§ 2), a modification of this simpler form seemed on physical grounds more likely to give a good approximation, and the object of the work described in this paper was to examine this modification and see how good an approximation could be obtained with it. We make use of some results of Hylleraas in the earlier stages of this work.

[1] J. C. Slater, *Phys. Rev.*, **35,** 210, 1930.
[2] V. Fock, *Zeit. f. Phys.*, **61,** 126, 1930.
[3] D. R. Hartree, *Camb. Phil. Soc.*, **24,** 89, 111, 1928.
[4] E. Hylleraas, *Zeit. f. Physik*, **54,** 347, 1929; **65,** 209, 1930. These papers will be referred to as H I, H II, respectively.

§ 2. THE FORM OF THE APPROXIMATE WAVE FUNCTION.

Let r_1, r_2, r_{12} be the distances of the two electrons of a helium-like atom from the nucleus, and the distance between them, respectively. Then, for the normal state, the wave function Ψ is a function of r_1, r_2, r_{12} only, and is independent of the three angle variables defining the plane of the triangle containing the nucleus and the electrons, and the azimuth of the triangle in its plane.[1] Further, the wave function for this state must be a symmetrical function of the positions of the two electrons.



To the approximation commonly used in the treatment of the many-electron atom, we would neglect the dependence of Ψ on r_{12} and use

$$\Psi = \psi(r_1)\psi(r_2) \quad . \quad . \quad . \quad . \quad (1)$$

as an approximate wave function. The solution given by the variation principle for this type of wave function with the ψ's unrestricted is given by the self-consistent field calculation already carried out by one of us,[2] and the solution given by this approximation with the ψ's specified as exponential functions, viz. :—

$$\Psi = e^{-k(r_1+r_2)} \quad . \quad . \quad . \quad . \quad (2)$$

is given by Hylleraas (*loc. cit.*, H I).

With a wave function of this type, the relative probabilities of one electron being in different places are independent of where the other electron is, and this is inconsistent with the existence of forces between the electrons ; or more analytically a function of this type does not satisfy the wave equation on account of that potential energy term in the equation which expresses the repulsion of the electrons and which is a function of r_{12}.

[1] See H I.

[2] D. R. Hartree, *loc. cit.* For the energy value see J. A. Gaunt, *Proc. Camb. Phil. Soc.*, **24**, 332, 1928, and D. R. Hartree and M. M. Black, *Proc. Roy. Soc.*, **139**, 311, 1933, footnote on p. 332.

We can try to take the dependence on r_{12} into account by trying a wave function of the type

$$\Psi = \psi(r_1)\psi(r_2)\theta(r_{12}). \qquad (3)$$

It would be possible to use this approximation with the second method of applying the variation principle, leaving the functions ψ and θ to be determined; but this is rather elaborate, and it seemed best to restrict the wave function still further by specifying definite analytical forms for ψ and θ, and to use the first method. As far as ψ is concerned, this restriction is probably not serious: the results of approximation (1) can be represented very closely by an exponential function for ψ, so an exponential function for ψ is likely to be a good approximation with a function Ψ of form (3) as well; and as far as θ is concerned, the results of the work show that the restriction to a definite analytical form is not important here either.

In using this method of applying the variation principle, there are two points to be considered in choosing the analytical form of the function to be tried; firstly the function should be of such a form that the evaluation of the integrals $\int\Psi^*\mathrm{H}\Psi d\tau$, $\int\Psi^*\Psi d\tau$ is practicable and leads to comparatively simple algebraic expressions, and secondly it should be likely to give a good approximation to the actual wave function, as the determination of the best approximate function of a given form is hardly worth doing if that best is still going to be a poor approximation. To help in the choice of a promising wave function, physical arguments may be of assistance.

The simplest functions, from the first point of view, are exponentials, polynomials, and products of these two types of functions. The results of approximations of the type (1) have already suggested that ψ should be exponential, so we take

$$\Psi = Ce^{-k(r_1+r_2)}\theta(r_{12})$$

and now consider the analytical form to take for $\theta(r_{12})$.

Hylleraas has already used an approximation of this type with

$$\theta(r_{12}) = e^{\gamma r_{12}} \qquad (4)$$

but this seems unsatisfactory on physical grounds. The forces between two electrons tend to zero as $r \to \infty$, so that it would be expected that for large r_{12}, $\theta(r_{12})$ should not become exponentially large, but should rather tend to a *constant* value, describing the fact that for large distances apart the relative probabilities of one electron being in different places are nearly independent of where the other is.

Consider now the form of $\theta(r_{12})$ for r_{12} small. Using atomic units,[1] and transforming to r_1, r_2, r_{12} as independent variables, the wave equation for a helium-like atom of nuclear charge N is (see H I) :

$$\left[\frac{\partial^2}{\partial r_1^2} + \frac{2}{r_1}\frac{\partial}{\partial r_1} + \frac{\partial^2}{\partial r_2^2} + \frac{2}{r_2}\frac{\partial}{\partial r_2} + 2\frac{\partial^2}{\partial r_{12}^2} + \frac{4}{r_{12}}\frac{\partial}{\partial r_{12}} + \frac{r_1^2 - r_2^2 + r_{12}^2}{r_1 r_{12}}\frac{\partial^2}{\partial r_1 \partial r_{12}} + \frac{r_2^2 - r_1^2 + r_{12}^2}{r_2 r_{12}}\frac{\partial^2}{\partial r_2 \partial r_{12}} + 2\left\{\frac{N}{r_1} + \frac{N}{r_2} - \frac{1}{r_{12}}\right\}\right]\Psi = -2E\Psi \quad . \quad . \quad (5)$$

Now for r_{12} small, $r_1 - r_2 = O(r_{12})$, so that putting

$$\theta(r_{12}) = r_{12}^s(a_0 + a_1 r_{12} + \ldots), \ (a_0 \neq 0)$$

we get the indicial equation

$$s(s+1) = 0,$$

the terms in the equation involving $\partial^2\Psi/\partial r_1 \partial r_{12}$, $\partial^2\Psi/\partial r_2 \partial r_{12}$ not contributing to the lower order terms in r_{12}. The term Ψ/r_{12} in the equation, arising from the mutual repulsion of the electrons, also does not contribute to the lowest order term in r_{12}, so that, rather unexpectedly, we have $s = 0$, i.e. $\theta(r_{12}) = O(1)$ for r_{12} small, whereas physical intuition would rather suggest that $\theta(r_{12}) \to 0$ as $r_{12} \to 0$ on account of the mutual repulsion between the two electrons.

Thus we see that if we are going to use an approximation

[1] I.e. unit of length $a_H = h^2/4\pi^2 me^2$, unit of charge e, unit of mass m. The unit of energy is then $2hc$R, that is, twice the ionisation energy of the hydrogen atom.

Hylleraas uses unit of length $= a_H/2N$, unit of mass $2m$, unit of energy $= hc\mathrm{RN}^2$, which makes numerical alteration in the coefficients of some of the terms.

of the type (3) at all, we would expect $\theta(r_{12})$ to have the properties

$$\theta(r_{12}) = \mathrm{O}(1)$$

both for small r and for large r.

Two parameters at least are required to describe such a function; one to give the ratio of its values at $r_{12} = 0$, and $r_{12} = \infty$, and the other to describe the linear scale of the variation from one value to the other.

A function with these properties, and satisfying the conditions of analytical simplicity for the evaluation of the integrals, is

$$\theta(r_{12}) = b - ae^{-k\beta r_{12}}.$$

Approximation (2) is given by $a = 0$ (or $\beta = 0$), Hylleraas' approximation (4) by $b = 0$; we will put $b = 1$ (since an arbitrary multiplying factor, which disappears on normalisation, can be taken out of θ). Thus we are led to the form

$$\Psi = Ce^{-k(r_1+r_2)}(1 - ae^{-k\beta r_{12}}) \quad . \quad . \quad (6)$$

as a promising approximate wave function for helium-like atoms, k, a, β being parameters to be determined by the variation method and C being the normalisation constant.

With one more parameter to choose than in Hylleraas' simple wave function

$$\Psi = C'e^{-k(r_1+r_2)}e^{k\beta r_{12}} \quad . \quad . \quad . \quad (7)$$

we would expect to get a better approximation, and with a wave function whose behaviour for r_{12} large is physically more reasonable, a considerable improvement was expected. Actually the improvement is not great, but this negative result is itself of some interest and value, as will appear in the discussion.

§ 3. Application of the Variation Principle.

Writing for brevity

$$X = \int\Psi^*(2H)\Psi d\tau, \ Y = \int\Psi^*\Psi d\tau \quad . \quad . \quad (8)$$

the variation principle can be put in the alternative form

$$\delta(X/Y) = 0, \ (X/Y) = 2E \quad . \quad . \quad . \quad (9)$$

and with this form, the normalisation constant in the wave function cancels, and need not be further considered. Also since, in atomic units, the ionisation energy of the hydrogen atom is $\frac{1}{2}$, 2E is the total energy of the atomic system in units of the ionisation energy of the hydrogen atom. The value of X/Y obtained by substituting any approximate wave function Ψ will therefore be the value of the total energy in these units, calculated with this approximate wave function. For a helium-like atom, $-2H\Psi$ is the expression on the left-hand side of equation (5).

Following Hylleraas, we can eliminate the parameter k in the wave function to be tried, as follows. We choose the other parameters so that k, r_1, r_2, r_{12} only appear in the combinations kr_1, kr_2, kr_{12} (a factor k has been written explicitly in the exponent of the term $ae^{-k\beta r_{12}}$ in (6) for this reason). Then we write

$$s = k(r_1 + r_2) \,.\, t = k(-r_1 + r_2),\ u = kr_{12}$$
$$\Psi(r_1, r_2, r_{12}) = \phi(s, t, u)$$

and ϕ will then not depend explicitly on k.

Then writing

$$K = \tfrac{1}{8}\iiint u(s^2 - t^2)\phi^2 dt\,du\,ds \qquad (10)$$
$$L' = 2\iiint su\,\phi^2\, dt\,du\,ds \qquad (11)$$
$$L'' = \tfrac{1}{2}\iiint (s^2 - t^2)\phi^2\, dt\,du\,ds \qquad (12)$$
$$M = \iiint \Big[u(s^2 - t^2)\Big\{\Big(\frac{\partial\phi}{\partial s}\Big)^2 + \Big(\frac{\partial\phi}{\partial t}\Big)^2 + \Big(\frac{\partial\phi}{\partial u}\Big)^2\Big\}$$
$$+ 2s(u^2 - t^2)\frac{\partial\phi}{\partial s}\frac{\partial\phi}{\partial u} + 2t(s^2 - u^2)\frac{\partial\phi}{\partial u}\frac{\partial\phi}{\partial t}\Big] dt\,du\,ds \quad (13)$$

the range of integration being

$$0 < t < u\,;\ 0 < u < s\,;\ 0 < s < \infty,$$

we have,[1] for a helium-like atom of atomic number N

[1] Cf. H II, formula (9). Our L′, L″, M, K are the functions L, L′, M, N of H II respectively; K has been used in place of N to avoid confusion with the atomic number. On account of the difference of units of length and of energy from those employed in H II (cf. footnote p. 74), the coefficients of L, K in X/Y are 2N and 4 times their values in H II, respectively.

$$\frac{X}{Y} = \frac{k^2M - 2kL}{4K} \quad . \quad . \quad . \quad (14)$$

where

$$L = NL' - L'', \quad . \quad . \quad . \quad (15)$$

and K, L, M are explicitly independent of k.

For X/Y to be stationary for variations of k, we must have

$$\frac{\partial}{\partial k}\left(\frac{X}{Y}\right) = 0$$

whence

$$k = L/M$$

and substituting this value of k in (14), we obtain [1]

$$\frac{X}{Y} = -\frac{L^2}{4KM} \quad . \quad . \quad . \quad (16)$$

This elimination of k simplifies the determination of the other parameters considerably.

We thus require to find the minimum value of $-L^2/4KM$ where K, L, M are given by (9) to (13) and (15), with

$$\phi = e^{-s/2}(1 - ae^{-\beta u}) \quad . \quad . \quad . \quad (17)$$

§ 4. Evaluation of a Useful Integral.

In evaluating the integrals K, L, M with wave functions of the form (17), we meet integrals of the form

$$I_{l,\,n} = \int_{s=0}^{\infty}\int_{u=0}^{s} e^{-s-\beta u}\, s^l u^n du\, ds \quad . \quad . \quad (18)$$

where l, n are integral; and it is convenient first to obtain a general formula for integrals of this type.

For the integration with respect to u we have

$$\int_{u=0}^{s} u^n e^{-\beta u} du = \frac{n\,!}{\beta^{n+1}}\left[1 - e^{-\beta s}\sum_{m=0}^{n}\frac{(\beta s)^m}{m\,!}\right]$$

[1] For helium this result agrees with formula (16) of H I, as for N = 2, our L is twice the L of H I, and our unit of energy is 1/4 the unit used in H I, so that X/Y should be 4 times as large.

and multiplying by $s^l e^{-s}$ and integrating from $s = 0$ to ∞, we have, after a little reduction,

$$\mathrm{I}_{l,n} = \frac{n!\,l!}{\beta^{n+1}(\beta+1)^{l+1}}\left[(\beta+1)^{l+1} - \sum_{m=0}^{n}\frac{(m+l)!}{m!\,l!}\left(\frac{\beta}{\beta+1}\right)^m\right] \quad . \quad (19)$$

We can simplify this as follows. We have

$$\sum_{m=0}^{\infty}\frac{(m+l)!}{m!\,l!}x^m = (1-x)^{-(l+1)} \,. \quad . \quad (20)$$

and in (19) we have the sum of the first n terms of the series in (20), with $x = \beta/(\beta+1)$.

Now from (20),

$$\sum_{m=0}^{n}\frac{(m+l)!}{m!\,l!}x^m = (1-x)^{-(l+1)} - \sum_{m=n+1}^{\infty}\frac{(m+l)!}{m!\,l!}x^m$$

so

$$(1-x)^{l+1}\sum_{m=0}^{n}\frac{(m+l)!}{m!\,l!}x^m = 1 - \frac{(n+l+1)!}{l!\,n!}x^{n+1}\mathrm{P}_{l,n}(x) \quad (21)$$

where

$$\mathrm{P}_{l,n}(x) = \frac{n!}{(n+l+1)!}(1-x)^{l+1}\sum_{m=0}^{\infty}\frac{(m+n+l+1)!}{(m+n+1)!}x^m$$

But in (21) the left-hand side is a polynomial of degree $n+l+1$ in x, so $\mathrm{P}_{l,n}(x)$ must be polynomial of degree l.

From (21) we can construct a recurrence formula relating the functions $\mathrm{P}_{l,n}(x)$ for successive values of l, from which expressions for these functions can be written down at once.

We have from (21)

$$x^{n+1}\mathrm{P}_{l+1,n}(x) - x^{n+1}\mathrm{P}_{l,n}(x)$$

$$= -\frac{l!\,n!}{(n+l+2)!}\left[(n+1)+(1-x)^{l+1}\left\{(1-x)\sum_{m=0}^{n}\frac{(m+l+1)!}{m!\,l!}x^m - (n+l+2)\sum_{m=0}^{n}\frac{(m+l)!}{m!\,l!}x^m\right\}\right]$$

$$= -\frac{l!\,(n+1)!}{(n+l+2)!}\left[1-(1-x)^{l+1}\sum_{m=0}^{n+1}\frac{(m+l)!}{m!\,l!}x^m\right]$$

$$= -x^{n+2}\mathrm{P}_{l,n+1}(x)$$

whence

$$P_{l+1,\,n}(x) = P_{l,\,n}(x) - xP_{l,\,n+1}(x) \quad . \quad . \quad (22)$$

Also

$$P_{0,\,n}(x) = \frac{1}{n+1}$$

so using (22) we have in succession, for higher values of l,

$$\left.\begin{aligned}
P_{1,\,n}(x) &= \frac{1}{n+1} - \frac{x}{n+2} \\
P_{2,\,n}(x) &= \frac{1}{n+1} - \frac{2x}{n+2} + \frac{x^2}{n+3} \\
P_{3,\,n}(x) &= \frac{1}{n+1} - \frac{3x}{n+2} + \frac{3x^2}{n+3} - \frac{x^3}{n+4} \\
P_{4,\,n}(x) &= \frac{1}{n+1} - \frac{4x}{n+2} + \frac{6x^2}{n+3} - \frac{4x^3}{n+4} + \frac{x^4}{n+5}
\end{aligned}\right\} \quad (23)$$

and from the recurrence formula (22) it is easy to see generally that the coefficients of $\frac{1}{n+1}, \frac{x}{n+2}, \frac{x^2}{n+3}$ ... are the coefficients in the binomial expression of $(1-x)^l$.

Putting $x = \beta/(\beta+1)$ in (21) we have

$$\sum_{m=0}^{n} \frac{(m+l)}{m!\,l!}\left(\frac{\beta}{\beta+1}\right)^m = (\beta+1)^{l+1}$$
$$\left[1 - \frac{(n+l+1)!}{l!\,n!}\left(\frac{\beta}{\beta+1}\right)^{n+1} P_{l,\,n}\left(\frac{\beta}{\beta+1}\right)\right]$$

so substituting in (19) we obtain for the values of the required integral (18)

$$I_{l,\,n} = \frac{(n+l+1)!}{(\beta+1)^{n+1}} P_{l,\,n}\left(\frac{\beta}{\beta+1}\right) \quad . \quad . \quad (24)$$

§ 5. Evaluation of the Integrals K, L, M.

We require the values of the integrals (10) to (13) with the approximation (17) to the wave function ϕ, namely

$$\phi = e^{-s/2}[1 - ae^{-\beta u}].$$

Since ϕ is independent of t, the integration with respect to t from 0 to u can be carried out directly, leaving

$$K = \tfrac{1}{8}\int_{s=0}^{\infty}\int_{u=0}^{s} u^2(s^2 - \tfrac{1}{3}u^2)\phi^2 du\, ds$$

$$L' = 2\int_{s=0}^{\infty}\int_{u=0}^{s} su^2\phi^2 du\, ds$$

$$L'' = \tfrac{1}{2}\int_{s=0}^{\infty}\int_{u=0}^{s} u(s^2 - \tfrac{1}{3}u^2)\phi^2\, du\, ds$$

$$M = \int_{s=0}^{\infty}\int_{u=0}^{s}\left[u^2(s^2 - \tfrac{1}{3}u^2)\left\{\left(\frac{\partial\phi}{\partial s}\right)^2 + \left(\frac{\partial\phi}{\partial u}\right)^2\right\} + \tfrac{4}{3}su^3\frac{\partial\phi}{\partial s}\frac{\partial\phi}{\partial u}\right]du\, ds$$

and for the helium atom we have N = 2, so that from (15)

$$\begin{aligned} L &= 2L' - L'' \\ &= \int_{s=0}^{\infty}\int_{u=0}^{s}(4su^2 - \tfrac{1}{2}s^2u + \tfrac{1}{6}u^3)\phi^2\, du\, ds \end{aligned}$$

and the results of the further integrations with respect to u and s can be put down directly using the formulæ (23), (24) of the previous section.

Since the integrals K, L, M are quadratic in ϕ, and ϕ is linear in a, the integrals are quadratic in a, so it is convenient to write

$$\left.\begin{aligned} K &= K_0 - K_1 a + K_2 a^2 \\ L &= L_0 - L_1 a + L_2 a^2 \\ M &= M_0 - M_1 a + M_2 a^2 \end{aligned}\right\} \qquad . \qquad . \qquad (25)$$

where K_0, K_1, K_2, etc., are functions of β only. The expressions for these integrals are found to be

$$\left.\begin{aligned} K_0 &= 4, \quad K_1 = \frac{8+5\beta+\beta^2}{(1+\beta)^5}, \quad K_2 = \frac{4+5\beta+2\beta^2}{(1+2\beta)^5} \\ L_0 &= 27, \quad L_1 = \frac{2(27+4\beta-\beta^2)}{(1+\beta)^4}, \quad L_2 = \frac{27+8\beta-4\beta^2}{(1+2\beta)^4} \\ M_0 &= 8, \quad M_1 = \frac{2(8+15\beta+3\beta^2)}{(1+\beta)^5}, \\ & \qquad M_2 = \frac{2(4+15\beta+22\beta^2+20\beta^3+8\beta^4)}{(1+2\beta)^5} \end{aligned}\right\} \qquad (26)$$

We require the values of a and β which make

$$\frac{X}{Y} = -\frac{L^2}{4KM}$$

a minimum, and the minimum value of this quantity.

For the approximate wave function $\Psi = e^{-k(r_1+r_2)}$, in which k is the only parameter, $X/Y = -L_0^2/4K_0M_0 = -729/128$, and it is convenient to express X/Y as a multiple of the value given by this approximation. Thus we write

$$\frac{X}{Y} = -\frac{729}{128}J(a, \beta) \qquad . \qquad . \quad (27)$$

where

$$J(a, \beta) = \frac{(L/L_0)^2}{(K/K_0)(M/M_0)} \qquad . \qquad . \quad (28)$$

K, L, M being given by (25), (26); and we require the maximum value of J.

Also the value of the parameter k is given by

$$k = L/M = \frac{27}{8}\frac{L/L_0}{M/M_0}.$$

§ 6. Determination of the Maximum Value of J.

The function J depends on the parameters a, β in such a complicated way that it is not practicable to determine its maximum directly by solving the equations $\frac{\partial J}{\partial a} = 0$, $\frac{\partial J}{\partial \beta} = 0$ for a and β.

The values of a and β giving the maximum value of J were therefore located approximately by a graphical method, at first by plotting J as a function of β for different values of a, and later by plotting J as a function of a for given values of β, as this was found more convenient for the numerical work.

To give a general survey of the behaviour of function J, curves of J as a function of β on a small scale are shown in Fig. 1; and curves of J as a function of a in the neighbourhood of the maximum are shown on a larger scale in Fig. 2. The

curve marked $a = \infty$ in Fig. 1 corresponds to Hylleraas' simple wave function (7).

From these figures the following results are evident :—

(*a*) For $a = 1$, J has no maximum between $\beta = 0$ and ∞. Since for $a = 1$, $\theta(r_{12}) = 1 - ae^{-k\beta r_{12}}$ is zero for $r_{12} = 0$, this result confirms the conclusion of § 2 that $\theta(r_{12})$ is of order of unity at $r_{12} = 0$ and does not become zero.

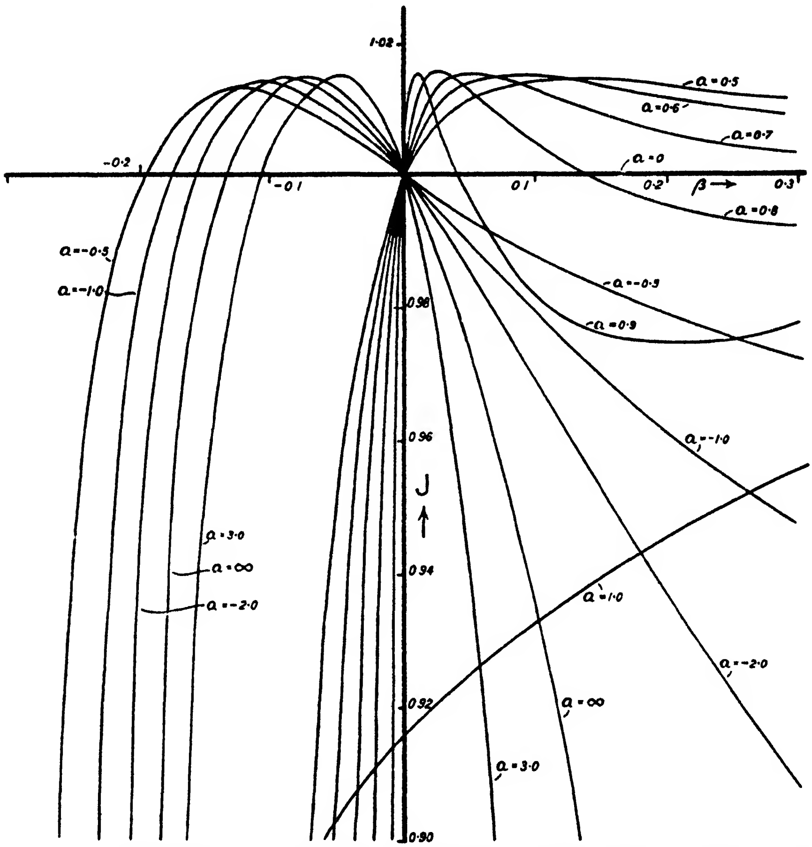


FIG. 1.—Showing J (a, β) as a function of β for various values of a

(*b*) The maximum value of J, however, occurs for a fairly small value of $1 - a$, and for a small value of β, and its value is about 1·0153.

(*c*) The maximum of the envelope of the (J, a) curves is rather flat, so that the best value of β is not very sharply determined.

(*d*) For each value of β, the maximum of the (J, a) curve occurs at about a value of $\beta = (1 - a)/8$.

(*e*) It is possible to obtain nearly as large values of J with negative values of $(1 - a)$ and β, as with small positive values.

The fact that the values of $1 - a$ and β giving the maximum value of J are both small means that a better determination of the maximum directly from (25), (26), (28) is not going to be satisfactory; for when $a = 1$, $K = K_0 - K_1 + K_2$ and

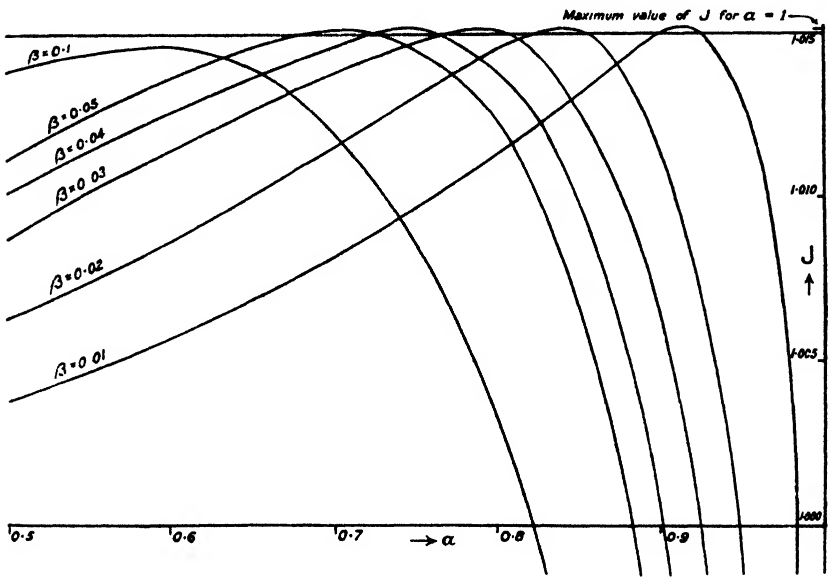


FIG. 2.—Showing J as a function of a for different values of β, in the neighbourhood of the maximum of J.

this is of order β^2 for β small, whereas K_0, $\frac{1}{2}K_1$, and K_2 are all about 4; so that if K were calculated directly from (25), (26) for small values of $1 - a$ and β, it would be calculated as a small difference between two nearly equal quantities of opposite sign, and it is well known that this is unsatisfactory in numerical work. Similar comments apply also to L, M.

The possibility that further difficulties in the numerical work may arise when $1 - a$ and β are small is suggested by the fact that the limit of J as $1 - a$ and β both tend to 0 depends on the order in which they tend to 0.

We have in fact $J(a, 0) = 1$ for $a \neq 1$, so that

$$\underset{a \to 1}{Lt}\ J(a, 0) = 1.$$

But for $\beta \neq 0$

$$J(a, \beta) = \frac{(L_0 - L_1 + L_2)^2}{(K_0 - K_1 + K_2)(M_1 - M_1 + M_2)} \frac{K_0 M_0}{L_0^2}$$

and expanding the expression (26) in powers of β

$$\begin{aligned} K_0 - K_1 + K_2 &= 96\beta^2 + O(\beta^3) \\ L_0 - L_1 + L_2 &= 506\beta^2 + O(\beta^3) \\ M_0 - M_1 + M_2 &= 128\beta^2 + O(\beta^3) \end{aligned}$$

whence

$$\underset{\beta \to 0}{Lt}\ J(1, \beta) = \cdot 9146 \neq \underset{a \to 1}{Lt}\ J(a, 0).$$

And further if $1 - a$, β tend to 0 together, the limit of J depends on the ratio in which they tend to 0.

This, and the result (*d*) above, suggest that it may be more convenient to work in terms of the ratio $\beta/(1 - a)$ than with a itself, in locating the maximum of $J(a, \beta)$.

Further, if K is written as a quadratic in $(1 - a)$ instead of in a, viz. :—

$$K = (K_0 - K_1 + K_2) + (K_1 - 2K_2)(1 - a) + K_1(1 - a)^2$$

then $(K_0 - K_1 + K_2)$ is of order β^2 for small β, as we have seen above, and $(K_1 - 2K_2)$ is of order β, and similarly for L and M. So if we write

$$\left.\begin{aligned} &(K_0-K_1+K_2)/\beta^2K_0=\kappa_0,\ (K_1-2K_2)/\beta K_0=\kappa_1,\ K_2/K_0=\kappa_2 \\ &(L_0-L_1+L_2)/\beta^2L_0=\lambda_0,\ (L_0-2L_2)/\beta L_0=\lambda_1,\ K_2/L_0=\lambda_2 \\ &(M_0-M_1+M_2)/\beta^2M_0=\mu_0,\ (M_1-2M_2)/\beta M_0=\mu_1,\ M_2/M_0=\mu_2 \end{aligned}\right\} \quad (29)$$

κ_0, κ_1, κ_2, etc., are functions of β remaining finite and non-zero at $\beta = 0$. If we write also

$$\beta/(1 - a) = y \qquad . \quad . \quad . \quad (30)$$

we have

$$K/K_0 = (1 - a)^2[\kappa_0 + \kappa_1 y + \kappa_2 y^2]$$

and similarly for L and M ; and so

$$J = \frac{[\lambda_0 + \lambda_1 y + \lambda_2 y^2]^2}{[\kappa_0 + \kappa_1 y + \kappa_2 y^2][\mu_0 + \mu_1 y + \mu_1 y^2]} \qquad (31)$$

and in this form it is practicable to evaluate J without difficulty for values of β and $(1 - a)$ as near zero as we require. Also using the expansions of κ_1, κ_2, etc., we have for small β

$$\frac{1}{\beta}\left[\frac{35}{4} - \kappa_1\right] = 72 + O(\beta), \frac{1}{\beta}\left[\frac{208}{27} - \lambda_1\right] = \frac{1518}{27} + O(\beta), \frac{1}{\beta}\left[\frac{25}{4} - \mu_1\right] = 44 + O(\beta).$$

and the left-hand side of each of these expressions is a convenient quantity to use in interpolation of κ_1, etc., for small β if required; κ_0, λ_0, μ_0 can also be easily interpolated, and κ_2, λ_2, μ_2 constructed from $\kappa_2 = 1 - \beta\kappa_1 - \beta^2\kappa_0$.

If we put into (31) the values of κ_0, κ_1, κ_2, etc., for $\beta = 0$ this expression shows how the limit of J as $a \to 1$, $\beta \to 0$ depends on the ratio $y = \beta/(1 - a)$.

The location and determination of the maximum value of J was done in two ways. First, curves of J as function of y for given β were plotted, and for each the maximum value of J, and the value of y for which it occurs, were estimated, with the results shown in Table I.

TABLE I.

β	Value of y for max. J	Max. J
0·00	0·096	1·01520
0·01	0·112	1·01527
0·02	0·127	1·01526
0·03	0·142	1·01523

Then for each β, the maximum J for that β was plotted against β, and the maximum, and value of J for which it occurs, were again estimated. This gave for the maximum

$$J = 1{\cdot}01527 \text{ at about } \beta = 0{\cdot}01_3,\ y = 0{\cdot}11_6.$$

The corresponding value of k is 3·679. The third decimal both in β and in y is uncertain to several units; it could be determined more accurately if the numerical work were carried through to higher accuracy, but the improvement on Hylleraas' simple wave function is not enough to justify the labour.

Secondly the curves of J as a function of y, which were used

for the location of the maximum by the method already mentioned, were also used to interpolate the values of y for which J has specified values, and from this information contours of constant J were sketched on a diagram with β and y as co-ordinates. The contour diagram, in the neighbourhood of

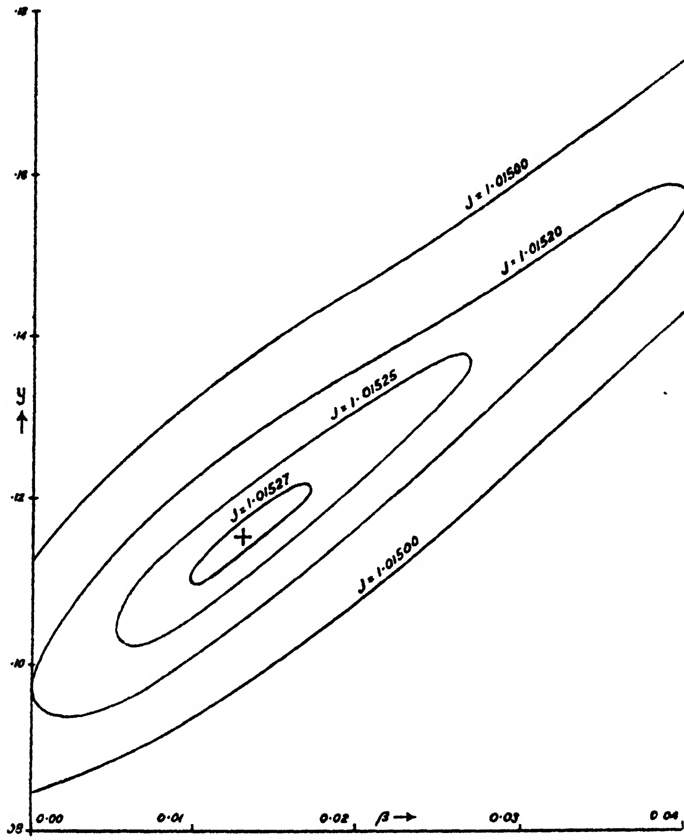


FIG. 3.—Contour diagram for the function J in the neighbourhood of the maximum. The approximate position of the maximum is marked with a cross +. $y = \beta/(1 - a)$.

the maximum, is shown in Fig. 3; it does not enable the maximum to be located any more accurately, but it shows the general behaviour of the function near the maximum, and illustrates, what is already clear from the results given above, that the determination of β is not at all sharp; the contour diagram shows a "ridge" running in the direction

of β and y increasing, and the value of J on this ridge only varies slowly with β, especially in the direction of β increasing from the value which gives the maximum.

§ 7. Discussion of the Result.

It is interesting to compare the different energy values given by different approximations to the wave function. Such a comparison is made in Table II.; here (*c*) is Hylleraas' simple wave function (7) and (*d*) is the wave function obtained by the work here described. For the interest of the comparison, the results for two more elaborate wave functions (*e*), (*f*) examined by Hylleraas are also given; we have only been concerned to try and improve the approximation to the way in which Ψ depends on r_{12}, whereas in these wave functions

Table II.

Wave Functions.

(*a*) $e^{-k(r_1+r_2)/2}$. $(k = 27/8 = 3{\cdot}375.)$

(*b*) $\psi(r_1)\psi(r_2)$, best function ψ without restriction on analytical form (method of self-consistent field).

(*c*) $e^{-k(r_1+r_2)/2}e^{k\gamma r_{12}}$.

(*d*) $e^{-k(r_1+r_2)/2}(1 - ae^{-k\beta r_{12}})$.

(*e*) $e^{-k(r_1+r_2)/2}e^{\gamma r_{12}}\cosh \alpha k(r_1 - r_2)$.

(*f*) $e^{-k(r_1+r_2)/2}[1 - c_1 k r_{12} + c_2 k^2 (r_1 - r_2)^2 + c_3 k(r_1 + r_2) + c_4 k^2 (r_1 + r_2)^2 + c_5 k^2 r_{12}^2]$.

For values of constants in wave functions (*c*), (*d*), (*e*), (*f*), see text and H I, H II. For functions ψ in wave function (*b*), see Hartree, *Proc. Camb. Phil. Soc.* (*loc. cit.*).

2E = total energy of helium atom as multiple of ionisation energy of hydrogen atom.

$-4 - 2E$ = ionisation energy of neutral helium atom in normal state, in same units.

Calculated values of $2E = \int\Psi(2H)\Psi d\tau / \int\Psi^2 d\tau$.

Wave Function	2E	−4−2E	Difference from Observed Value
(*a*)	−5·6953	1·6953	0·1118
(*b*)	−5·73	1·73	0·077
(*c*)	−5·7792	1·7792	0·0279
(*d*)	−5·7823	1·7823	0·0248
(*e*)	−5·7988	1·7988	0·0083
(*f*)	−5·8066	1·8066	0·0005
Experimental	−5·8071	1·8071	——

(*e*), (*f*) an improvement is made in the dependence on r_1, r_2 as well.

In taking a variation of Ψ with r_{12} containing one more parameter than Hylleraas' simple wave function (*c*), and also with a more physically reasonable behaviour for r_{12} large, we expected to obtain a considerable improvement in the calculated value of 2E; actually the improvement is only small, namely ·0031 out of a total difference of ·0280 from the experimental value, or not much more than 10 per cent. improvement.

It is interesting to enquire into the reason of the smallness of the improvement attained. A clue to the explanation of this is afforded by the insensitiveness of the value of J to the value of β, and by the fact that small negative values of β can give almost as "good" wave functions as small positive values of β, although the behaviour of the wave function for large r_{12} is essentially different according as β is positive or negative. This shows that the dependence of $\theta(r_{12})$ on r_{12}, for r_{12} large, is not of primary importance to the approximation given by the wave function considered. The reason for this is clear when we consider the whole approximate wave function

$$\Psi = e^{-k(r_1+r_2)/2}(1 - ae^{-k\beta r_{12}}).$$

Since $r_{12} \not> (r_1 + r_2)$, r_{12} can only be large when $r_1 + r_2$ is large, and so even if β is negative, then as long as $(\frac{1}{2} + \beta)$ is positive and not too small, the $e^{-k(r_1+r_2)}$ factor in Ψ will be predominant for large r_{12}, and Ψ will be negligibly small for $(r_1 + r_2)$ greater than about $10/k$, whatever the value of β above this limit.

Generalising this argument we see that so long as Ψ does not diverge too rapidly as $r_{12} \to \infty$ (r_{12} being here considered as a variable which can formally take any value independent of r_1, r_2), it does not much matter how it behaves for r_{12} large; the approximation depends primarily on its behaviour with r_{12} for r_{12} small. This explains why almost as good a result can be obtained with a wave function of the type (*c*) as with one of the type (*d*).

For comparing our wave function (*d*) with Hylleraas' simple wave function (*c*), it is convenient to multiply it by

such a factor (which can be taken out of the normalising factor) as to make $\theta(r_{12}) = 1$ at $r = 0$. When this is done, and a is expressed in terms of y by the substitution $a = 1-(\beta/y)$ (cf. formula (30) defining y), the factor in the wave function (d) depending on r_{12} becomes

$$\theta(r_{12}) = 1 + \frac{y-\beta}{\beta}(1 - e^{-k\beta r_{12}})$$
$$\sim 1 + (y-\beta)kr_{12} \qquad \text{for } r_{12} \text{ small}$$

and $y - \beta = 0{\cdot}10_3$. For comparison wave function (c) gives

$$\theta(r_{12}) = e^{\gamma k r_{12}}$$
$$\sim 1 + \gamma k r_{12} \qquad \text{for } r_{12} \text{ small.}$$

with $\gamma = {\cdot}07$.

Thus for small r_{12}, the variation of the wave functions (c) and (d) with r_{12} are similar; the numerical coefficients certainly differ by a factor of $1{\cdot}5$, but a close agreement would not be expected. With Hylleraas' wave function (c), higher powers of r_{12} in the expansion of the exponential may be appreciable over part of the relevant range, and are positive. The small value of β we have found with our wave function (d) shows that these higher powers of r_{12} are actually not as large as would be given by wave function (c), and it is reasonable than that the coefficient of the linear term should be smaller with (c) than with (d), to compensate for the positive contributions from the higher powers of r_{12}.

It should be noted, too, that in the limit $\beta = 0$, with $y \neq 0$, our $\theta(r_{12})$ becomes the linear function

$$\theta(r_{12}) = 1 + ykr_{12}$$

exactly. Table. I. shows that this one-parameter linear function for $\theta(r_{12})$ is very little less good than the two-parameter function

$$\theta(r_{12}) = 1 + \frac{y-\beta}{\beta}(1 - e^{-k\beta r_{12}}),$$

and is better than wave function (c).

The bearing of these results on work on other atoms is that they show that when we try to take into account approximately the dependence of the wave function on the

mutual distances between pairs of electrons, there is no object in going beyond the simplest analytical expressions for this dependence, and that of the two simple expressions, exponential and linear, the linear is the better (as well as leading to the simpler formulæ) ; the main further improvements in the approximation to the wave function come from improving its dependence not on the mutual distance but on the positions of the individual electrons, as in Hylleraas' wave functions (*e*), (*f*) for the helium atom.

§ 8. SUMMARY.

On physical and analytical grounds a function

$$\phi = e^{-k(r_1+r_2)/2}[1 - ae^{-k\beta r_{12}}],$$

is proposed as likely to be a good simple approximation to the wave function of the neutral helium atom in its normal state. The best values of the parameters k, a, β are determined by the variation method.

The improvement over Hylleraas' simple wave function

$$\Psi = e^{-k(r_1+r_2)/2}e^{k\beta r_{12}}$$

is found to be small. The reason for the smallness of the improvement is discussed; it is shown that since r_{12} cannot be large unless either r_1 or r_2 is large, and this is on account of the way the wave function depends on r_1, r_2, the form of the variation of $\theta(r_{12})$ with r_{12} for r_{12} large is (within limits) unimportant, and these two wave functions show much the same dependence on r_{12} for r_{12} small.

From the results it is concluded that for work on other atoms, taking into account the dependence of the wave functions on the mutual distances between electrons, a linear expression for this dependence will afford an adequate approximation.

VII.—A Practical Method for the Numerical Solution of Differential Equations.

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INTRODUCTION.

FOR the approximate calculation of atomic structures by the method of the self-consistent field,[1] it has been necessary to develop a method for the numerical integration of the differential equations concerned, which is rapid and easy to carry out accurately, and which includes adequate current checks on the work, so that any computing error is found and rectified before much further work is based on results affected by it. Further, the method must be applicable to differential equations involving functions specified by tables, not only to functions whose analytical form is given.

The method at present used was arrived at after considerable experience and trial of different methods in this and other problems, and has proved very satisfactory in practical use. As used in the self-consistent field calculations, it is limited to ordinary equations of the second order with the first derivative absent, of the form

$$\frac{d^2y}{dx^2} = f(x, y)$$

where $f(x, y)$ is any smooth function of x and y (in particular, it need not be linear in y); but very many equations arising in the application of mathematics to diverse branches of

[1] D. R. Hartree, *Proc. Camb. Phil. Soc.*, Vol. 24, pp. 89, 111, 1928. These papers will be referred to as I and II.

science and technology arise directly in this form, or are easily reduced to it, so this limitation still leaves a wide range of possible applications of the method to equations of practical importance, and a method found particularly suitable in one problem involving an equation of this form may be found applicable to other problems, so that it seems desirable to give a somewhat detailed account of this method.

The account here given is based on the first part of a typescript drafted, and revised from time to time, for distribution to research students and others working on the calculation of self-consistent fields, and desiring a detailed account of the computing technique involved. The notation and some of the terminology suitable for this application is retained here, but can easily be translated if required into that appropriate to other applications.

The method is easily extended to simultaneous second order equations with the first derivatives of all variables absent, such as the equations of a coupled system with a general potential energy function, or the equations of propagation of an electromagnetic wave in a stratified doubly refracting medium.

1. CENTRAL DIFFERENCES.

If a function f of a single variable x is tabulated at equal intervals δx of x, we may define the operator δ by

$$\delta f(x) = f(x + \tfrac{1}{2}\delta x) - f(x - \tfrac{1}{2}\delta x) \quad . \quad . \quad (1)$$

δ is the operation of taking the difference between successive entries in a table of f; this operation is commutative with $\frac{d}{dx}$ and $\int dx$, and it can also be repeated, thus

$$\begin{aligned}\delta^2 f(x) = \delta[\delta f(x)] &= \delta f(x + \tfrac{1}{2}\delta x) - \delta f(x - \tfrac{1}{2}\delta x) \\ &= f(x + \delta x) - 2f(x) + f(x - \delta x) \quad (2)\end{aligned}$$

(*Note.*—Read $\delta^2 f$ as "second difference of f.")

Reckoning x from a fixed origin x_0, we can write for shortness

$$f(x_0 + n\delta x) = f_n \quad . \quad . \quad . \quad (3)$$

so that from a table of f at equal steps of δx from x_0 we can form differences:

$$\left.\begin{aligned} \delta f_{n+\frac{1}{2}} &= f_{n+1} - f_n \\ \delta^2 f_n &= \delta f_{n+\frac{1}{2}} - \delta f_{n-\frac{1}{2}} = f_{n+1} - 2f_n + f_{n-1} \end{aligned}\right\} \quad . \qquad (4)$$

etc., and the "difference table" shown in Table I.[1] A

TABLE I.

DIFFERENCE TABLE.

x . . .	$x_0 - 2\delta x = x_{-2}$		$x_0 - \delta x = x_{-1}$		x_0		$x_0 + \delta x = x_1$		$x_0 + 2\delta x = x_2$	. . .
f . . .	f_{-2}		f_{-1}		f_0		f_1		f_2	. . .
δf		$\delta f_{-1\frac{1}{2}}$		$\delta f_{-\frac{1}{2}}$		$\delta f_{\frac{1}{2}}$		$\delta f_{1\frac{1}{2}}$		. . . .
$\delta^2 f$ . . .	$\delta^2 f_{-2}$		$\delta^2 f_{-1}$		$\delta^2 f_0$		$\delta^2 f_1$		$\delta^2 f_2$	. . .
$\delta^3 f$		$\delta^3 f_{-1\frac{1}{2}}$		$\delta^3 f_{-\frac{1}{2}}$		$\delta^3 f_{\frac{1}{2}}$		$\delta^3 f_{1\frac{1}{2}}$		. . . .
$\delta^4 f$ . . .	$\delta^4 f_{-2}$		$\delta^4 f_{-1}$		$\delta^4 f_0$		$\delta^4 f_1$		$\delta^4 f_2$	. . .

numerical example is shown in Table II. The set of differences with suffixes defined by (4) are called "central differences."[2]

TABLE II.

x	2·8		2·9		3·0		3·1		3·2		3·3
$f=1/x$	·35714		·34483		·33333		·32258		·31250		·30303
δf		−1231		−1150		−1075		−1008		−947	
$\delta^2 f$			+81		+75		+67		+61		
$\delta^3 f$				−6		−8		−6			

The successive differences of a function tabulated at equal steps of the independent variable provide a sensitive test for errors in the tabulated values, as any error in a tabular entry is exaggerated in the higher orders of differences. This can be seen by forming a difference table for a function F which is equal to f except for one value which is different

[1] The table can, of course, be written with successive values of x in a column; this is in fact the usual form, but in view of the most convenient way of arranging the work for the numerical integration of a differential equation, it is as well to get accustomed to it with the values of x in a row.

[2] For a fuller account of central differences and their applications, see Whittaker and Robinson, *Calculus of Observations*, Ch. III, IV.

by ϵ; the values of f may be considered as the true values of the function, and ϵ as an error in a single tabular value. The difference table is shown in Table III. (the coefficients of ϵ

TABLE III.

x	x_{-2}		x_{-1}		x_0		x_1		$x_2 \dots$
F ...	f_{-2}		f_{-1}		$f_0+\epsilon$		f_1		$f_2 \dots$
δF ...		$\delta f_{-1\frac{1}{2}}$		$\delta f_{-\frac{1}{2}}+\epsilon$		$\delta f_{\frac{1}{2}}-\epsilon$		$\delta f_{1\frac{1}{2}}$	$\dots$
δ^2F ...	$\delta^2 f_{-2}$		$\delta^2 f_{-1}+\epsilon$		$\delta^2 f_0-2\epsilon$		$\delta^2 f_1+\epsilon$		$\delta^2 f_2 \dots$
δ^3F ...		$\delta^3 f_{-1\frac{1}{2}}+\epsilon$		$\delta^3 f_{-\frac{1}{2}}-3\epsilon$		$\delta^3 f_{\frac{1}{2}}+3\epsilon$		$\delta^3 f_{1\frac{1}{2}}-\epsilon$	$\dots$
δ^4F ...	$\delta^4 f_{-2}+\epsilon$		$\delta^4 f_{-1}-4\epsilon$		$\delta^4 f_0+6\epsilon$		$\delta^4 f_1-4\epsilon$		$\delta^4 f_2+\epsilon \dots$

in the successive rows are the binomial coefficients). As the successive orders of differences generally decrease rapidly if the tabular interval δx is small enough for the table to be of any practical use, and the effects of an error increase in successive orders, these effects become obvious on inspection in the higher orders of difference. This use of differences for checking purposes is an essential feature of the method of numerical integration to be described.

The tabulation of a function to a finite number of significant figures involves an error in each tabular entry (unless the function can be evaluated exactly), and these errors make the higher orders of differences noticeably irregular. This must be remembered in using differences to check values of a function which has been calculated: for example, the third differences of $1/x$ in the above table indicate errors which could only be rectified by retaining another significant figure. In general each tabulated entry may be more or less in error in this way, so the irregularities in the higher order of differences are not related in a simple way as they are if only one entry is in error, and some experience is necessary before one can say at sight whether a given set of somewhat irregular differences probably does or does not indicate an error of magnitude affecting the last significant figure retained. But errors of 2 or more in the last significant figure make themselves unmistakably evident, and the behaviour of the differences then usually makes it possible to locate the error and estimate its magnitude.

2. FORMULÆ FOR INTEGRATION, DIFFERENTIATION AND INTERPOLATION.

Various relations between the differences of a function, its derivatives and their differences, and various interpolation formulæ involving these quantities, can be obtained. Only those which are used in the calculations to be described will be given here. It must be realised that these formulæ are only approximate, though with the tabular interval δx usually taken in practice, terms involving higher differences are negligible.

(*a*) *Interpolation.*

The only interpolation required in most cases is "half-way" interpolation, that is interpolation for $x = x_0 + \frac{1}{2}\delta x$. This is the simplest of all interpolations, and the formula is most conveniently used in the form

$$f_{\frac{1}{2}} = f_0 + \tfrac{1}{2}\delta f_{\frac{1}{2}} - \tfrac{1}{16}(\delta^2 f_0 + \delta^2 f_1) + \tfrac{3}{256}(\delta^4 f_0 + \delta^4 f_1) + \dots \quad (5)$$

For other interpolations on the few occasions when they are required, probably the most satisfactory method is to take proportional parts of the first difference and use Everett's formula[1] for the contributions from the higher orders of differences.

(*b*) *Integration.*

$$\delta f_{\frac{1}{2}} = \int_{x_0}^{x_0+\delta x} f' dx = \overline{f'}\delta x = (2\overline{f'})(\tfrac{1}{2}\delta x) \quad . \quad (6)$$

where[2]

$$2\overline{f'} = (f'_0 + f'_1) - \tfrac{1}{12}(\delta^2 f'_0 + \delta^2 f'_1) + \tfrac{11}{720}(\delta^4 f'_0 + \delta^4 f'_1) + \dots \quad (6.1)$$

$$= (f'_0 + f'_1) - \tfrac{1}{6}\delta f''_{\frac{1}{2}}\delta x + \tfrac{1}{360}\delta^4 f'_0 + \dots \quad . \quad (6.2)$$

These give the increment of a function in an interval in terms of its derivatives at the beginning and end, and their differences. The first form is the more generally useful, and is given in the exact form which has been found most

[1] See Whittaker and Robinson, *op. cit.*, § 25. A useful table of coefficients in interpolation formulæ has been computed and published by E. Chappell.

[2] *Cf.* I, § 9, formulæ (9·1), (9·2).

convenient for numerical work. The second is convenient when the derivative of the integrand is available, on account of the small coefficient of δ^4 (which is usually the first term neglected).

Similarly we may express the second difference of f in terms of f'' and its differences.

$$\delta^2 f_0 = (\delta x)^2[f''_0 + \tfrac{1}{12}\delta^2 f''_0 - \tfrac{1}{240}\delta^4 f''_0 + \ldots] \quad . \quad (7)$$

This is an exceedingly useful formula and forms the basis of the method to be described for the numerical integration of second order differential equations.

(*c*) *Differentiation.*

$$2(\delta x) f'_0 = \delta f_{\frac{1}{2}} + \delta f_{-\frac{1}{2}} - \tfrac{1}{6}(\delta x)^2(\delta f''_{\frac{1}{2}} + \delta f''_{-\frac{1}{2}}) \quad . \quad (8)$$

In the only case in these calculations in which it is necessary to evaluate the derivative of a function from its differences, its second derivative is also known, and this is the most convenient formula to use.

3. INTEGRATION OF SECOND ORDER EQUATION WITH FIRST DERIVATIVE ABSENT.

In evaluation of the integral of a *given* function, the successive differences of the integrand are all known before the integration is started; the feature which makes numerical integration of differential equations a more elaborate process is that this is no longer the case.

The most important equation which has to be solved numerically in the determination of the self-consistent field of an atom is of the form

$$\frac{d^2\mathrm{P}}{dr^2} + \mathrm{F}(r)\mathrm{P} = 0$$

in the notation usually adopted, and this is a second order equation with the first derivative absent. This form of equation happens to be the most convenient for numerical solution; it is actually more convenient than a first order equation. (That it is also linear is in principle not an important factor in the numerical work.)

Such an equation is integrated through a succession of

equal intervals δr of r, the double integration from P'' to P being done directly, by application of (7). It is possible to integrate P'' once to get P' by (6.1) and then integrate P' to give P by (6.2),[1] but the process of double integration by (7) is numerically considerably easier and quicker, and is probably also more accurate, and is easier to check adequately. It happens that P' is only required for one value of r, so the fact that it is not explicitly calculated for all r is no drawback.

For the beginning of the integration some special method has to be used (e.g. use of a solution in series); we will for the present consider the procedure in the main part of the range of integration, where the question of starting the integration is not concerned.

If the integration has been completed to $r = r_0$, then we know P_0, P''_0, $\delta P_{-\frac{1}{2}}$, and for the interval r_0 to $r_0 + \delta r$, we have

$$\delta P_{\frac{1}{2}} = \delta P_{-\frac{1}{2}} + \delta^2 P_0 \quad . \quad . \quad . \quad (9)$$

$$\delta^2 P_0 = [P''_0 + \tfrac{1}{12}\delta^2 P''_0 - \tfrac{1}{240}\delta^4 P''_0](\delta r)^2 \quad . \quad (10)$$

[from (7)]. $\delta^2 P''_0$ depends on P''_1, which at this stage is not known, but it can be estimated from previous values, and as it is multiplied by a small coefficient $\frac{1}{12}$, it need not be estimated very accurately; this provides an approximate value of $\delta^2 P_0$, from which approximate values of $\delta P_{\frac{1}{2}}$ and P_1 are found; then from this P_1, P_1'' is calculated and this provides a better value of $\delta^2 P''_0$, and the same formulæ (9) (10) are used over again[2] (with the $\delta^4 P''$ term included if appreciable) to give

[1] A method based on this procedure was used in early calculations of self-consistent fields (an outline of this method is given in I, § 9).

[2] In the earlier method used in self-consistent field calculations (I, § 9), formulæ (9, 10) were used to give an estimate of P_1; for the suggestion that they should be used as formulæ for carrying out the main integration I am indebted to Professor C. Størmer who has developed a rather similar method (Oslo, Vidensk. Skrifter I, *Math. Naturw. Klasse*, 1913, No. 4), using, however, only the backwards differences $\delta^2 P''_{-1}$, $\delta^4 P''_{-2}$ . . . all of which are known at the beginning of the integration of the interval, so that no estimation is required. The coefficients of these backwards differences, however, converge much more slowly than those of the central differences $\delta^2 P''_0$, $\delta^4 P''_0$ . . ., and the additional step of making the estimate is so simple that it is worth while taking in order to enable (10) to be used.

a better value of P_1. The process is repeated if the value of P''_1 calculated from this value of P_1 is enough different from the previous approximate value to affect the value of $\delta^2 P_0$, but this is very seldom the case in practice, as the value of P''_1 only affects $\delta^2 P_0$ through the term $\delta^2 P''_0$ which occurs with the small coefficient $\frac{1}{12}$. However the full value of P''_1 will be required for calculating the next interval, so if necessary it should be recalculated with the better value of P_1 for this purpose, although the recalculation may not affect $\delta^2 P_0$ enough to affect P_1. It is nearly always possible to make the first estimate so accurately that no such recalculation is necessary.

$\delta^4 P''_0$ can only be found after one further interval has been calculated, but it occurs with such a small coefficient that the term involving it is usually negligible, and if it is appreciable, can be added when the value of $\delta^4 P_0''$ can be found. If the change it makes in P_1 is so big as to affect P_1'' enough to change subsequent values of $\delta^2 P$, it is usually an indication that smaller interval should be chosen.

If δP is calculated to adequate accuracy, P' can be found from it, for the one value of r for which P' is required, by using (8). The integration is taken *one interval beyond* the value of r for which P' is required, otherwise a formula with a larger error term has to be used. If P' were required for all values of r, it could be calculated either in this way, or by integration of $\int P''\,dr$ using (6), (6.1).

4. COMMENTS ON THE METHOD.

Several points may be made in connection with the above method.

(*a*) The value of $\delta^2 P''_0$ used in the main calculation depends on a value of P''_1 obtained through an estimate of P_1 and the use of the differential equation, *not* directly by extrapolation from previous values of P'' or $\delta^2 P''$. This is because P'' is sensitive to any peculiarities of $F(r)$, while P is very insensitive to them.

(*b*) The estimation required to give an approximate value of P''_1 is particularly easy to do when the equation to

be solved is a second order (not necessarily linear) equation with the first derivative absent. The second derivative required in the estimation is calculated in the course of the integration; if the first derivative were present it would also have to be estimated, and no method at the same time so simple and accurate is available without knowing the third derivative.

(*c*) In numerical work on a large scale, the adequate checking of the work is a very important consideration, especially when, as here, a serious mistake at one stage may vitiate all subsequent work. The successive differences of P'', tabulated for use in the integration formulæ, also provide such a check on this part of the work, and we also have available a very efficient check on most of the remainder of the work as follows.

Differencing (10) twice, we have

$$\delta^4 P_0 = [\delta^2 P''_0 + \tfrac{1}{12}\delta^4 P''_0 - \tfrac{1}{240}\delta^6 P''_0](\delta r)^2 \quad . \quad (11)$$

Comparison of values of $\delta^4 P$ calculated from this formula, with values obtained as the second differences of the calculated values of $\delta^2 P$, checks every stage of the work from the calculation of P'' to that of the differences of $\delta^2 P$. These values should not differ by more than one unit in the last significant figure retained; and if for two successive values of $\delta^4 P$ the differences between the values calculated in the two ways are in the same direction, it is probable that there is an error. It should be noted that although the term in $\delta^4 P$ may be negligible in (10), it may not be so in (11).

(*d*) The intervals δr should generally be kept of such a size that the contributions of $\delta^4 P''$ to $\delta^2 P$ are not more than 1 or 2 in the last figure retained. In practice it is usually best to keep well inside this limit, both in order to make the numerical work simple as a whole, and particularly to make satisfactory estimating easy, and, perhaps more important, also from the point of view of adequate checking. If the fourth differences are large and vary rapidly (as they usually do if the interval is taken of such a size that they are large) it may be difficult to recognise an irregularity due to an error when superposed on that rapid variation.

It would certainly be possible to use more elaborate procedure and formulæ for integration over larger intervals with adequate accuracy as far as the errors of the integration formulæ are concerned, but somewhat extensive experience leaves no doubt that a method involving only simple procedure and formulæ and a larger number of intervals is very much to be preferred to an elaborate method with a smaller number of intervals. Apart from the ease of working with simple formulæ, it is difficult to keep an adequate check on the numerical work unless the successive differences converge well enough to provide one; and in practical work this question of checking the numerical work adequately is a fundamental one. Also, in the particular application to the self-consistent field, the final solution is required at intervals at least as close as is given by the criterion stated above.

When, as in this case, the differential equation involves a function specified not by an analytical formula but by a table, it is very convenient to have a method in which it is only necessary to use the tabulated values of this function, so that no interpolation is needed.[1]

(*e*) The integration formulæ depend on the use of a succession of intervals of the same size, and the integration is carried out through a series of such intervals, but it is not necessary to use intervals of the same size throughout the whole calculation. The most convenient change is to double the size of the interval (in the case of the radial wave equation of the "self-consistent field" approximation to the structure of an atom, the permissible size of interval increases with r). The procedure is then straightforward; of the values of P'' and P already calculated, alternate values are taken to provide a set of differences with intervals of double length.

For numerical reasons, however, it is usually preferable to take intervals 1, 2, or 5 times a power of 10; the change of the interval length by a factor $2\frac{1}{2}$ involves some simple interpolation to provide the initial set of differences, but is

[1] In this respect the present method is much easier to work than methods of the Runge-Kutta type (see, for example, H. T. H. Piaggio, *Differential Equations*, Ch. VIII, §§ 86 *sqq.*), which involve interpolation.

otherwise straightforward. For example, suppose the equation has been integrated with intervals $\delta r = 0{\cdot}02$ up to $r = 0{\cdot}20$, and we wish to continue the integration with intervals of 0·05. We have the values of P″ and P at $r = 0{\cdot}10$, 0·12, 0·14, 0·16, 0·18, 0·20. Values of P″ and P at $r = 0{\cdot}15$ are interpolated using (5), and with the values at $r = 0{\cdot}10$ and 0·20 they provide two first differences and one second difference of P″ and also of P.

Since δP for the interval 0·20 to 0·25 is going to be obtained by adding δ^2P(0·20) on to δP for the interval 0·15 to 0·20, which depends on the *interpolated* value of P(0·15), and later values of δP are going to be obtained by adding successive δ^2P's, the whole result of the subsequent calculation depends on the interpolated value of P, so *it is essential to make the interpolation as accurately as possible, and to check rigorously the interpolated value.*

The check of the interpolated value can be done in two ways; firstly the interpolated value at $r = 0{\cdot}15$ and the previously calculated values at $r = 0{\cdot}14$, 0·16 provide one second difference δ^2P(0·15) with intervals $\delta r = 0{\cdot}01$. It should be checked that this is (very nearly) $\frac{1}{4}$ of the mean of δ^2P(0·14) and δ^2P(0·16) with intervals $\delta r = 0{\cdot}02$; and a similar check should also be applied to the interpolated value of P″.

Secondly δ^2P(0·15) for $\delta r = 0{\cdot}05$ should be calculated from the integration formula (10) and compared with the value deduced from the already known P(0·10), P(0·20) and interpolated P(0·15). The difference should not be more than 1 in the last significant figure.

Similar interpolation is required when, in the course of the integration, the interval length has to be halved.

This practice of providing an overlap between the calculations with different interval length, for checking purposes, should also be adopted when the interval length is doubled; e.g., in changing from $\delta r = 0{\cdot}01$ to $\delta r = 0{\cdot}02$ at $r = 0{\cdot}10$, the value of δ^2P(0·08) should be calculated from the integration formula and checked against the value obtained by taking alternate values of P (i.e. at 0·06, 0·08, 0·10) and differencing.

In judging where to change the interval size, it must be

remembered that if the interval is doubled, the nth order differences are multiplied by 2^n, and also that in order to keep the same accuracy in P and so in $\delta^2 P$, the accuracy required in P'' is greater.

(f) The method is equally suitable to the equation

$$\frac{d^2y}{dx^2} = f(x, y)$$

where $f(x, y)$ is not linear in y; the only difference is in the way in which $\frac{d^2y}{dx^2}$ is calculated from the estimate of y.

5. NUMERICAL EXAMPLE.

Several points will become clearer by detailed consideration of a numerical example.

An extract from a calculation is shown in Table IV.[1] Each column refers to a single value of r, first differences are written half-way between the columns for the initial and final values of r to which they refer. The lines are lettered for convenience in description of the work.

The equation in this case is

$$\frac{d^2P}{dr^2} + \frac{2Z_p}{r}P = 0$$

with $2Z_p$ given as a function of r (the radial wave equation for the Cs atom, with $l = 0$, $\epsilon = 0$), and the beginning of the calculation is shown. For $r = 0{\cdot}000$, $0{\cdot}002$, $0{\cdot}004$ the calculation is based on a solution in power series; from there onwards it is continued by the method of integration already described.

The *first* value of δP and the first *three* values of P'' are calculated from the values of P/r obtained from the power series; from these values of P'', $\delta^2 P(0{\cdot}002)$ is calculated by the usual integration formula (10), and added to the $\delta P(0{\cdot}001)$ to give $\delta P(0{\cdot}003)$, and finally $P(0{\cdot}004)$. This is then checked against the value calculated from the series, and from here the integration is carried on by the use of the integration formula (10) alone.

[1] Facing p. 106.

At this stage, only quantities above and to the left of the heavy line are known: the calculation proceeds as follows.

From the previous values of $\delta^2 P''$ we may guess that $\delta^2 P''(0{\cdot}004)$ will be about $-11{\cdot}_2$, so that $\frac{1}{12}$ of it will be about $-0{\cdot}_9$, and so, by (10), $\frac{1}{(\delta r)^2}\ \delta^2 P(0{\cdot}004)$ will be about

$$\begin{array}{ccc} P''(0{\cdot}004) & +\ \frac{1}{12}\,\delta^2 P''(0{\cdot}004) & \\ -\,856{\cdot}_3 & -\,0{\cdot}_9 & =\ -\,857{\cdot}_2. \\ \text{(already known)} & \text{(estimated)} & \\ \text{(line D)} & & \end{array}$$

This is done mentally and the result written in line S, and the result of multiplication by $(\delta r)^2$ is written in line T. This gives an approximate value of $\delta^2 P(0{\cdot}004)$, based on the estimated $\delta^2 P''(0{\cdot}004)$, and this value of $\delta^2 P(0{\cdot}004)$ is then added to $\delta P(0{\cdot}003)$ to give an approximate $\delta P(0{\cdot}005)$.

$$\begin{array}{llll} \delta P(0{\cdot}005) & =\ \delta P(0{\cdot}003) & +\ \delta^2 P(0{\cdot}004) & \\ & =\ {\cdot}01399 & -\ {\cdot}00343 & =\ {\cdot}01056 \\ & \text{(already calculated)} & \text{(line T)} & \\ & \text{(line Q)} & & \end{array}$$

which is written in line U, and added to the known value of P(0·004) to give an approximate value of P(0·006). (The estimate would provide a fairly reliable sixth decimal place in P, but since the full value of the first decimal in P″ is not being used in δ^2P, and the sixth decimal in P hardly affects the first in P″, there is no object in keeping the sixth decimal in the estimate.)

From the value of P so obtained, a value of P″ is calculated from the differential equation (line D) (this is the only step of the calculation for which a calculating machine or slide rule or log table is required: the other steps can be done mentally, although if a machine is available it can be used with advantage at other steps as well). The differences depending on this value of P are then written in (lines E, F, G: here the differences beyond the second are too small to be relevant).

Then the same calculation is repeated, but is now written

out more fully (lines I, J, K, L, Q, R) as it is likely to be the final calculation for this value of r, while the previous one was an approximation.

It will be seen that the estimate was correct to the accuracy required (and in fact to one significant figure more than required), and that no further calculation is necessary for this step.

The calculation has now reached a stage similar to that from which we started, only one value of r further on. The procedure can then be repeated for the next value of r.

When the calculations have been continued for one more value of r we can begin to use the check mentioned in § 4 (c) by differencing $\delta^2 P$ twice (lines M, N) and so getting the fourth differences of P (line N) and comparing it with the value calculated from (11) (line O). This checks all steps from line D to line O. The only parts of the calculation which are not thus checked are the successive additions of $\delta^2 P$ to give δP, and of δP to give P. These can be checked by calculating $\delta^2 P$ direct from the values of P by the formula,

$$\delta^2 P_0 = P_1 - 2P_0 + P_{-1}$$

the calculation being done on a machine. An alternative check, which can be applied whether or not a machine is available, is to add together a series of values of $\delta^2 P$ and check the result against the difference of the extreme values of δP; and the successive addition of δP to give P can be checked similarly.

When the integrand $f(x,y)$ of the differential equation

$$\frac{d^2 y}{dx^2} = f(x,y)$$

concerned is the sum of a number of terms, it is convenient, in calculating the sum, to write the values of the terms in the same *column* on the calculation sheet rather than in the same *row*, if the process of adding together the terms to form the sum is done mentally, as most people can add a set of numbers in a column more quickly and accurately than a set of numbers in a row. This is the reason why the calculations are arranged with a column, rather than a row, for each value of the independent variable.

When, however, a calculating machine is available there is not the same reason for this arrangement, and the alternative in which each *row* refers to one value of the independent variable is probably more compact and as easy to work.

6. Numerical Example: Change of Interval Length.

In starting an integration it is often advisable to take rather small intervals in order to be sure that for the first 3 values of r the available terms of an expansion in series are adequate (the form in which Z_p is given in the application considered is such that 4 terms of the series can be calculated as accurately as required, but not more). Once the integration has got started, it is usually practicable to use larger intervals, and this is the case in the example considered: so the integration is to be continued in steps $\delta r = 0{\cdot}005$ from 0·010.

The interpolation of P and P″ for $r = 0{\cdot}005$ is carried out as explained in § 4 (*e*), and checked by calculating δ^2P from the integration formula and from the interpolated value of P. Since an error of 0·5 in the last significant figure retained in P makes an error of 1 in this figure in the value of δ^2P, it is advisable for the purposes of this check to make the interpolation correct to 0·5 in the last figure retained: this is expressed, when necessary, by the unorthodox but very convenient notation of writing $\frac{1}{2}$ after the last significant figure: and since in the course of the work it is so often necessary to divide odd numbers by 2 (in units of the last significant figure retained), or numbers of the form $4n + 2$ by 4, that it is convenient to adopt this notation more generally: examples will be found in other parts of the calculation.

Thus before the calculation is extended beyond $r = 0{\cdot}010$, we have the information to the left of the broken heavy line, giving us a set of values of P″ and P with differences, checked by the agreement of δ^2P(0·005) calculated in two ways.

The first decimal in P″, while not yet being used to its full value to give five decimals in P, is being used more than before and so is now no longer written as a suffix. At the

next change of interval, to 0·01 (which in this calculation was made at $r = 0{\cdot}04$) it will be used to its full value.

No recalculation with a revised estimate of P was necessary in any value of r of the calculation shown in the example.

The check of values of $\delta^4 P$ is satisfactory: the differences between the values calculated in the two ways are never greater than $\frac{1}{2}$ in the last significant figure retained, and oscillate in sign as they should.

7. FIRST ORDER EQUATIONS.

For first order equations the procedure is much the same, except that there is no method at once so simple and accurate for making the estimate required for the calculations of the value of the integrand at the end of the interval.

If the equation is

$$y' = f(x, y)$$

a possible method, and perhaps the most satisfactory, would be to calculate y'' at each stage, and use the same method of estimating y at the end of the interval as was used for the second order equations.

For the first order forms of the wave equation, which are sometimes the most suitable forms to use, it has not so far seemed worth while introducing this calculation of y'': the method used is effectively to estimate $\delta y'$ from its previous values, and so estimate δy from (6.1) and hence the final value of y. This is done mentally and the actual work on the calculation sheet is done with this estimated final value of y, using (6.1) as the integration formula. [1]

The cruder method of estimating the final value of y

[1] With first order, as with second order, equations, it is possible to avoid the use of estimations altogether, by using an integration formula containing only backwards differences from the beginning of the interval; the method of integrating first order equations in this way is known as Adams' method (see Whittaker and Robinson, *op. cit.*, Ch. XIV).

The convergence of coefficients of the higher orders of difference with backwards differences is much slower than with central differences, and the use of the central difference formula (6·1) seems much preferable, for practical work, to the formally more satisfactory use of backwards differences in Adams' method.

means that an interval has to be recalculated with a revised estimate oftener than is the case with the second order equation.

8. Miscellaneous Notes.

(*a*) To remember the sign of the second difference term in the formulæ for single integration or interpolation, consider figure 1.

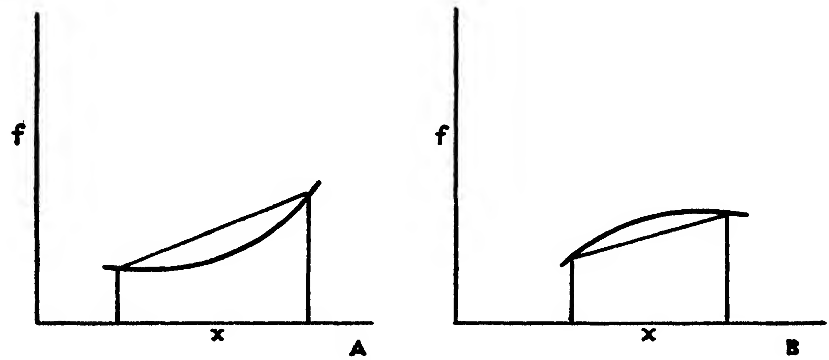

Fig 1.

Corresponding to A we have :—	and to B :—
$\dfrac{d^2f}{dx^2}\ +$	$\dfrac{d^2f}{dx^2}\ -$
$\delta^2 f\ +$	$\delta^2 f\ -$
Integration, $\bar{f}$ *less* than $\dfrac{f_0+f_1}{2}$	$\bar{f}$ *greater* than $\dfrac{f_0+f_1}{2}$
Interpolation, $f_{\frac{1}{2}}$ *less* than $\dfrac{f_0+f_1}{2}$	$f_{\frac{1}{2}}$ *greater* than $\dfrac{f_0+f_1}{2}$.

[*Note.* Since $$\delta^2 f = \frac{d^2f}{dx^2}(\delta x)^2 + O[(\delta x)^4],$$

the signs of $\delta^2 f$ and d^2f/dx^2 are the same whatever the sign of dx.]

(*b*) When one has become accustomed to the numerical work, it will not be found necessary to write in explicitly the decimal points in each line of the work: they should be kept in P, P″ and in the first one or two values of δP and δ^2P at each step where a change in δr is made, but elsewhere it is only necessary to write the significant figures.

VIII.—The Occurrence of the Genus *Platanus* in the Lough Neagh Clays and other Tertiary Deposits of the British Isles.

By T. Johnson, D.Sc., F.R.S.E.

Introductory.

In 1918 I began an examination of the fossil plants revealed in the core of the bore at Washing Bay at the S.W. corner of Lough Neagh where an attempt was made [1] to tap a concealed coalfield. The plants were found in an unexpected bed of clay, 1000 feet thick, at a depth between 760 and 930 feet. They are mostly well-preserved and yield tissue readily by the maceration method. Until 1921, when the change of Government came, I was assisted by Miss J. G. Gilmore and we published papers on *Sequoia* and *Dewalquea*. The Washing Bay inquiry led to inspection of collections of Tertiary plants from various other localities in the N.E. corner of Ireland, including the inter-basaltic plants of Ballypalady [2] from Co. Antrim, preserved partly in the "Gardner" collection in the Natural History Museum (B.M.), lent to me for examination and report in the first instance by Sir Arthur Smith Woodward, F.R.S., the Keeper of Geology; partly in the "Grainger" Collection in the Belfast City Museum, in addition to some specimens in other collections. During the past three years I have been given facilities in the Royal Scottish Museum, Edinburgh, to compare the Tertiary plants from the well-known locality of Ardtun, in the Isle of Mull,[3] with the Irish material. That there is some vagueness about the relative ages of the beds is evident from the literature on the subject. Thus Cole and Hallisey quote [4] the opinion of J. S. Gardner expressed in 1885, that the beds

of Co. Antrim are older than those of Mull, but in 1887 Gardner held the reverse view.[5] The beds in both countries are admittedly pre-Miocene, and Oligocene or Lower Eocene in age. Thus *Dewalquea*, new to Britain, is plentiful at Washing Bay, and occurs, I find, at Ballypalady also. It is not reported from Scotland. Except for one record—the Oligocene of Italy—it is not known on the continents of Europe or America later than the Eocene, the records being mostly from the Upper Cretaceous. In this paper I propose to confine my remarks to the genus *Platanus*.

Goeppert was the first to give, in 1845, an account[6] of a Tertiary Flora. He published in 1852 a list of 235 species from a locality (Schossnitz) in the neighbourhood of Breslau (51° N.). In this list he included six new species of the Plane tree—*Platanus* L. He concluded that the flora indicated a climate almost subtropical in character and was of a type suggestive of that in the South of N. America and N. Mexico. In 1851 Forbes published[3] his account of the fossil plants found at Ardtun in the Isle of Mull (56° 50″ N.) from a locality which the Duke of Argyll regarded as the site of a shallow marsh into which the leaves fell and became fossilised. They indicate a "warm fairly moist climate," warmer than that of to-day in the British Isles. One of the plants was named by Forbes *Platanites hebridicus*. He compared it with a *Platanus Hercules* which Unger had described[7] in 1847. Unfortunately this fossil proved not to be a *Platanus*, and may have led Gardner to suggest (I think incorrectly) that Forbes's name was a mere guess. Heer[8] pointed out in 1856, in his work on the fossil flora of Switzerland, the great importance of the Ardtun discovery as the first locality in the British Isles in which such "Miocene" plants had been found, and he urged its further exploration. He was particularly interested in the *Platanus* leaf, as he saw in it a likeness to a *Platanus* he found widely distributed through Switzerland and Central Europe generally, and to which he applied one of Goeppert's names—*P. aceroïdes*, on account of its likeness to the sycamore—*Acer*. Heer made the interesting observation that if specimens were found at Ardtun with a more pronounced marginal dentation than the figures (probably im-

perfect) indicated, then Forbes's name, published in 1851, must replace *P. aceroïdes* published in 1852, but without an accompanying description, I may add, until 1855.

Description of Species of Platanus.

The first detailed description of Forbes's *Platanus* did not appear until 1924, when Seward and Holttum published their *Revision*[9] *of the Ardtun Flora*, basing their account of this genus on several imperfect leaves in the Scottish Geological Survey Collections, collected by Tait, and on British Museum specimens. The many fine examples I have seen lately in the Hunterian Museum (" Koch " collection), University of Glasgow, in the Glasgow Art Galleries and City Museum, as well as in the Geological Museum in the Royal Scottish Museum, Edinburgh, show that the features Heer required to justify replacement of the name *P. aceroïdes* by *P. hebridica* (Forbes) were observable in Ardtun material. The name *P. aceroïdes* is so well established, and applied to leaves from so many parts of the world, that its replacement appears unlikely, especially as *P. hebridica* was for long undescribed.

Examination of Irish material adds considerably to our knowledge of the fossil representatives of the genus. A striking feature in a *Platanus* leaf is its expanded hollow base in which the winter-bud nestles. Schneider gives a detailed account of this in his Winter Studies. A leaf from Ballypalady preserved in the British Museum (*V.* 15231) illustrates this clearly (Pl. I, figs. 1, 2). In it the leaf appears detached from the stem with the resting bud still in its basal hollow. It thus seems to illustrate the time of year, late summer, when the leaf became fossilised, and to account also for the general absence of fruits at the site. The identification of the leaves of *Platanus* has been based hitherto on external characters only. The Irish material, more especially that from Washing Bay, has yielded tissue showing microscopic structure. The upper epidermis consists of cells with straightish lateral walls, without stomata. The under epidermis shows similar polygonal cells and, in addition, stomata (Pl. III, fig. 4), rounded in outline, 30-42μ in diameter, without

specialised subsidiary cells. Both leaf surfaces are markedly striate. The cuticular striæ on the surface of the guard-cells of the stoma run parallel to its pore and at right angles to the striæ on the surface of the surrounding epidermal cells. Such stomata and epidermis are exactly matched in the living Plane tree, *Platanus orientalis L.* of Greece and Asia Minor, etc., (Pl. III, fig. 3). Another diagnostic feature in the Plane leaf is the candelabra-hair of which Solereder [10] gives an illustrated account. It consists of a central axis of cells, increasing in length apically, carrying whorls of curved pointed cells, at the joints or cross-walls. Such candelabra-hairs are not infrequent in the Washing Bay core at levels at which the leaves of *Platanus* occur. They were always detached when found. This is not surprising, as they

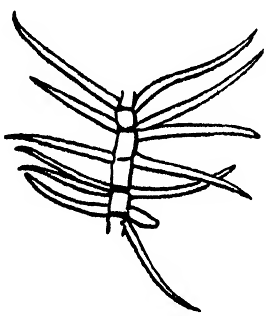

FIG. 1.—Drawing of candelabra-hair of *P. hibernica* (Washing Bay core, at 914 feet depth). The jointed axis is relatively stout and its appendages are in whorls of three (four in *P. occidentalis*), ($\times$ 240). Base and apex of axis missing.

normally become free early in living leaves. In one leaf found at the 914 feet level the hair shows five or six whorls of pointed cells (fig. 1).

Most readers will be familiar with the London Plane tree of our parks and avenues. It has long been known (Schneider, 1906) under the name of *P. acerifolia* [11] (*P. orientalis* $\times$ *P. occidentalis*), and was fully described by A. Henry [12] in 1920, as a hybrid. The stalked stipulate leaf of *Platanus* is normally palmately lobed, being 3- 5- 7-lobed, though occasionally, it is important to remember, it is scarcely at all lobed. Ettingshausen [13] gives a beautiful figure of the only old world species, *P. orientalis*. In the three-lobed leaf there are three primary veins, one into the tip of each lobe. The angle between the two primary lateral veins varies. In *P. orientalis* it averages a right angle (70°-115°), but in *P.*

occidentalis of N. America it is a wide obtuse angle. Another way of expressing this difference is to describe the middle lobe of *P. orientalis* as narrow, much longer than broad; while that of *P. occidentalis* is as broad as it is long. The base of the leaf in *P. orientalis* may be somewhat prolonged and attenuated beyond the point of divergence of the three primaries, giving it a tendency to a rounded-cuneate form. In *P. occidentalis* this prolongation is absent, the three primaries separate at the point of junction of petiole and lamina. These features are of importance in the investigation of the fossil leaves. From the underside of the primary laterals and from right and left of the midrib secondary veins are given off. All are craspedodrome and end in the upward curved teeth of the markedly sinuous-dentate edge. There is a considerable interval between the point of separation of the three primaries and the point of origin of the lowest pair of secondaries from the midrib. These secondaries do not fork to embrace the sinus between the lobes as is usually the case in *Acer*, a leaf with which *Platanus* has often been confused. The ultimate vascular reticulum has a characteristic appearance.

In his detailed and thorough account of *Platanus* in the Swiss flora Heer notes and illustrates the hybrid *P. acerifolia* (without realising it was a hybrid), and makes the interesting observation that *P. aceroïdes*, the fossil, agrees better with *P. acerifolia* than with *P. orientalis* and *P. occidentalis* unknown to him as its parents. *P. acerifolia* is a more vigorous tree than either of its parents, and *P. aceroïdes* is far more widely distributed than *Platanus* is to-day. In their description of *P. hebridica* Seward and Holttum state that Tait's specimens from Ardtun were all small, (5 × 5 cm.), and like the leaves of larger size in the British Museum, imperfect. The sinuous dentate edge of the living leaf is absent and only inconspicuous teeth are observable. There are, however, both in the Edinburgh Museum and in the Hunterian at Glasgow, fine leaves showing the curved teeth and sinuous edge as clearly as in *P. aceroïdes* and *P. acerifolia*. The most perfect leaf from Ardtun I have seen is one collected by Koch [14] in 1881 and preserved in the Hunterian Museum. Its leaf-stalk is 6 cm. long and shows the swollen hollow base in which

the resting bud lay. The lamina, clearly 3-lobed, was 14 × 12 cm. in extent. The base is rounded-cuneate and prolonged some 2 cm. beyond the point of junction of the primaries. The teeth are as pronounced as those figured by Heer in *P. aceroïdes.* The angle of divergence between the primary laterals is 80°, as it is in *P. aceroïdes* also, in Heer's figures generally. In a leaf from Ardtun, which Gardner gave to the Edinburgh Museum, the lamina measures 20 × 20 cm. and, when complete, was probably 24 cm. long. The angle of divergence is 80°. Berry mentions American fossil leaves three times this size.*

While the Irish leaves will, I think, from the features described, be accepted as *Platanus* leaves, it remains to attempt to assign to them an appropriate name. The Ballypalady leaf (*V.* 15231), as the photograph shows, is imperfect and its edge is missing. It was apparently three-lobed, and its primary laterals make an angle of 90° with one another. The lamina was prolonged downwards giving a somewhat cuneate base. The cross-anastomoses are well-pronounced. The lamina was 15 × 15 cm. in extent, and roughly orbicular in outline. I propose to name this leaf *Platanus hibernica.* The leaves in the Washing Bay core are smaller and less perfect, being only 5-6 cm. in length. They are also lacking in clear lobation, being ovate-orbicular in form. The teeth of the sinuous edge are well developed, (Pl. III, fig. 5). These leaves agree best with the variety of *P. aceroïdes* originally given specific rank by Goeppert as *P. Guillelmae* and as such frequently recorded by Lesquereux and others [15] from the American Tertiary. There is, e.g. very little difference between the leaf from a depth of 897 feet at Washing Bay (Pl. II, fig. 2, Pl. III, fig. 2), and Lesquereux's figure of *P. Guillelmae* in his sixth Annual Report, U.S.A. Survey (Pl. XLIV, fig. 1). I propose to distinguish this unlobed leaf as *P. hibernica*, var. *Guillelmae.* At a depth of 914 feet in the core there is a leaf of *Platanus* which in general appearance is so like a *Populus* that I was inclined for some time to place it in that genus. The craspedodrome venation and marginal

* An Ardtun leaf in the Nat. Hist. Mus. (B.M.) is 37 cm. long.

dentation, as well as the occurrence of a candelabra-hair at the same level, not to mention the microscopic structure, decided me in favour of a reference of it to *Platanus* as *P. hibernica* var. *populoides* (Pl. III, fig. 1). It is important to note that *Platanus occidentalis* under certain conditions of growth possesses leaves scarcely or not at all lobate, merely with short irregular dentate lobes, a condition very similar to the fossil form *P. Guillelmae.* I must refer readers to the account Seward and Holttum give of the distribution in time and space of *Platanus* and of the various types of leaves recorded. Let it suffice here to state that the genus has become in the course of time restricted in variety of form and area of distribution, tending to migrate southwards. It is recorded from the Cretaceous of the Arctic regions, N. America and Bohemia, appearing as late as the Pleistocene [16] in Europe.* Mull was regarded as the limit southwards of *Platanus.* The Irish stations are several degrees further south. Seward and Holttum consider that the type of leaf named *P. hebridica* disappeared early, not being recorded later than the Eocene. Berry attributes the absence of *Platanus* from the Eocene of S.E. North America and S. Europe to the warmth of the climate.

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* Saporta's figures of leaves of *P. aceroïdes* from the Miocene of the Rhone valley are strikingly like *P. orientalis* (f. 22[1]) and *P. occidentalis* (f. 22[2]) as figured by A. Henry.

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DESCRIPTION OF PLATES.

PLATE I.

FIGS. 1 and 2. *Platanus hibernica* sp. n., from Ballypalady, showing dormant axillary bud, *lb*, ($\frac{1}{1}$). Three overlapping leaves are shown. The middle leaf demonstrates the expanded base of the leaf-stalk. In Fig. 2 the bud is clear.

PLATE II.

FIG. 1. Trilobed leaf of *Platanus hibernica*, from Ballypalady, Co. Antrim, ($\frac{1}{1}$). Edge mostly imperfect.

FIG. 2. *Platanus hibernica*, var. *Guillelmae*. Washing Bay, Co. Tyrone, 908 feet depth, ($\frac{1}{1}$).

PLATE III.

FIG. 1. *P. hibernica*, var. *populoides*. Washing Bay, 914 feet depth, ($\frac{1}{1}$).

FIG. 2. Another impression of *P. hibernica*, var. *Guillelmae* Counterpart of leaf (Pl. II, fig. 2).

FIG. 3. Stomata of *P. orientalis* L., lower epidermis, ($\times$ 240).

FIG. 4. Stomata of *P. hibernica*, lower epidermis, ($\times$ 240).

FIG. 5. Edge of leaf of *P. hibernica* enlarged to show the curved teeth.

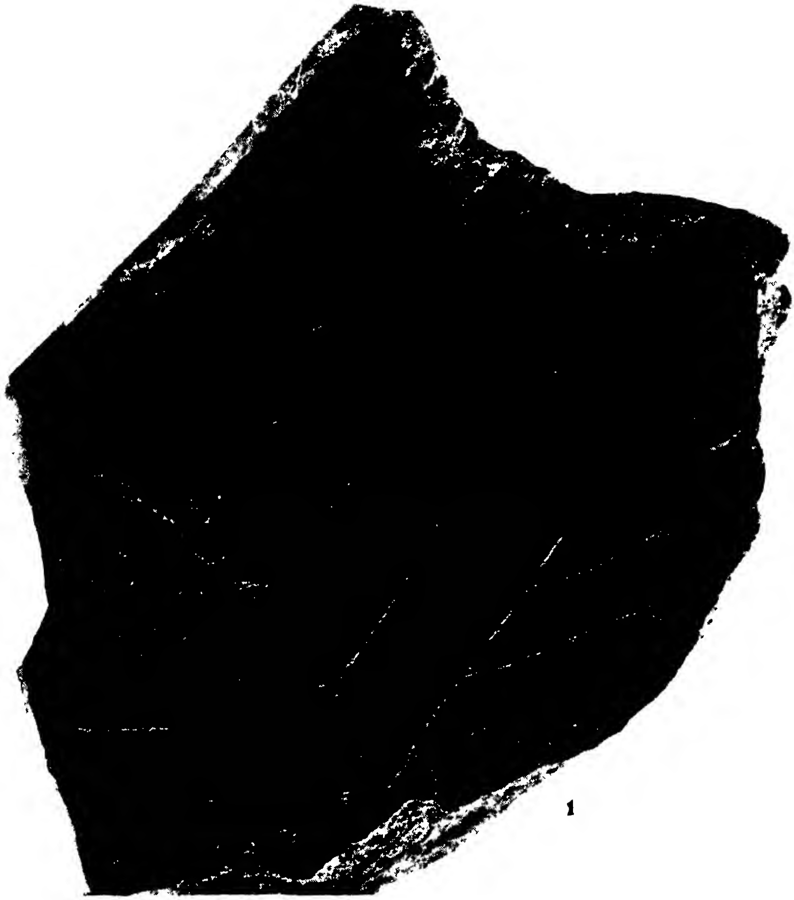
—*lb.*

1

lb.—

2

PLATE I.



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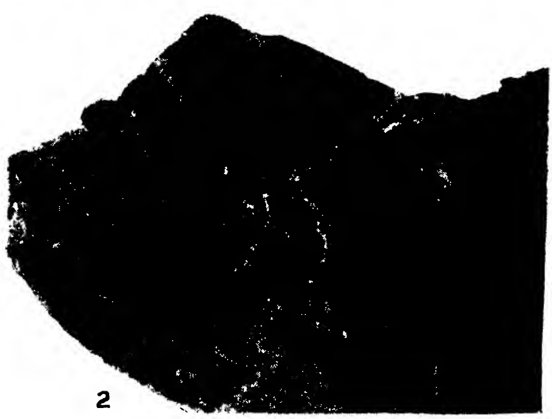

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PLATE II.

1

2

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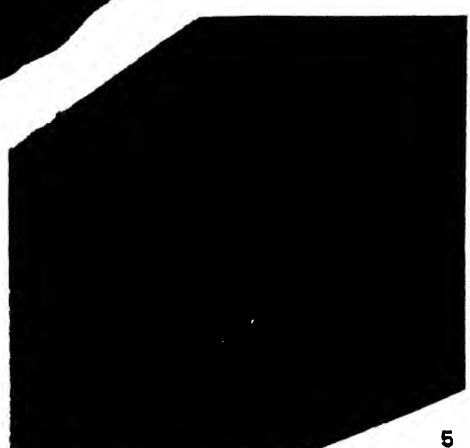

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PLATE III.

PROCEEDINGS OF THE MANCHESTER LITERARY AND PHILOSOPHICAL SOCIETY.

Obituaries.

By the death of Henry Sidebottom at "Sherwood," Bramhall, Cheshire, on the 8th of September, 1932, in his 82nd year, Great Britain lost one who was the last of the old school of British Protozoologists. He was born at "Crowcroft," Longsight, near Manchester, on the 14th April, 1851, the youngest child and seventh son of the late Alderman James Sidebottom, J.P., and his wife, Mary Ann Slater. He married in 1876 Fanny Elizabeth, fourth daughter of the late Alderman Thomas Booth, J.P. of "Harelands," Rochdale. His friend, Dr. Chaster of Southport, was the means of his first taking up the study of those organisms upon which he became an acknowledged authority. His sister-in-law was the wife of the late Charles Henry Nevill of Bramall Hall, Cheshire, a keen traveller, who brought back with him from his cruises in the *Victoria* much marine biological material. Sidebottom was an expert manipulator, and speedily amassed a very valuable collection of Foraminifera, which is now incorporated with, and forms part of the Heron-Allen and Earland Collections at the Natural History Museum at South Kensington, to which he presented it some years ago. His most important contributions to science were authoritative studies of the Foraminifera of (*a*) the Island of Delos, 1904-9 (Grecian Archipelago), (*b*) Palermo (Sicily), 1910, both published in the *Memoirs of the Manchester Literary and Philosophical Society*, (*c*) the "South-West Pacific Ocean," 1895 and 1913, published in the *Journal* of the Queckett Microscopical Club, and (*d*) "The East Coast of Australia," 1918, published in the *Journal* of the Royal Microscopical Society. He was in constant correspondence with the great authorities on the subject, Joseph Wright, of Belfast; Fortescue W. Millett,

of Marazion; and H. B. Brady, besides notable foreign authorities, such as Fornasini of Bologna, and Silvestri of Milan, whose experience and advice were always at his disposal. His works were profusely illustrated with his own drawings, and he was a man of many hobbies. His wife, three sons, one of whom is a violinist of rank, and a daughter, survive him. He was of a gentle disposition and a peace-maker, quietly genial and much loved.

John Thomas was born at Harlech in 1886, and was educated at Harlech Primary School, Barmouth County School, University College of Wales, Aberystwyth, and Trinity College, Cambridge. At all stages in his educational progress he made a strong impression among the teachers with whom he came into contact, and in 1910 he was awarded a post-graduate research exhibition, which held at Trinity until 1911. He published several papers on organic chemistry while working at Aberystwyth and Cambridge. In 1911 he became a research chemist in the Aeronautical Department of the National Physical Laboratories, and in 1912 he was made one of the research chemists at Nobel, Ltd., Ardeer. His original work was recognised by the University of Wales with the Degree of D.Sc. In 1918 he became chief chemist of the Solway Dyes Company, and in 1923 his position was changed to that of managing director of what had by this time become Scottish Dyes, Ltd. In 1926 Scottish Dyes, Ltd., was absorbed by the Imperial Chemical Industries, Ltd., and he was made joint managing director of the dyestuffs group of that organisation, and held this post until his death. He was particularly successful in adapting the results of delicate laboratory work to processes of manufacture on a large scale, and his keen criticisms, always conveyed with disarming modesty and kindliness, were highly valued by fellow-workers in scientific fields, as well as by business men, on whom he made a deep impression. His fertile and ingenious mind was a delightful feature, both in his scientific work and in his many contacts, both within and outside the scientific field. He became President of the Royal St. David's Golf Club at Harlech, and had a host of friends in this connection also. He was a man of simple tastes, and a genial and understanding companion, as well as an outstanding personality; and his many friends mourn his early death at Wilmslow, in January, 1933.

H. J. F.

The sudden death of Thomas Alfred Coward, on 29th January, 1933, is a heavy loss to all students and lovers of nature, especially to those of the Manchester district in which his busy and useful life was spent. He was born at Bowdon in 1867, and his keen interest in living creatures was encouraged by his father, Thomas Coward, who was an active member of the Manchester Natural History Society. After his schooldays at Brooklands, Sale, T. A. Coward was a student of the Owens College. He was in a Manchester bleachers' business for nearly twenty years; then he found himself able to give all his time and energies to the natural history of his home district and of any regions which he had opportunity of visiting. As a field naturalist he was one of the keenest in observation, scrupulously careful in his records, and with a sound scientific instinct and a wide knowledge which rendered his field work fruitful in scientific results. Best known as an ornithologist, he was an authority on all the vertebrate classes, and had a close acquaintance with insects, molluscs and plants. In the course of his active life he was able to add to the varied observation grounds in Britain which he knew full well, several Continental tracts, and he always made the most of his opportunities of study. The results of these appeared in a series of papers in scientific periodicals—including the *Manchester Memoirs*—and in such systematic books as the *Vertebrate Fauna of Cheshire*. He wrote also a number of valuable review articles, and many standard books on zoology. His well-known *Birds of the British Isles and their Eggs*, to quote the appreciation of a close naturalist friend, "has had a wider circulation than any bird book of our time, and has, more than any other in this country, promoted the study of birds as living creatures."

Coward joined the Manchester Literary and Philosophical Society in 1906; his colleagues honoured him and his work by electing him President for the years 1921-23. He was an attractive lecturer and an excellent nature-photographer. For more than thirty years he was associated with the Manchester Museum in which he did a vast amount of useful and unselfish work, especially in connection with the large collection of birds. From 1913 till his death he was a member of the Museum Committee, and for two periods (1916-19 and 1922-23) he served as Acting Keeper. No one who had the privilege of working with Coward could fail to recognise and admire his great knowledge, his conscientious accuracy, his readiness to help, and his unfailing friendliness and comradeship.

G. H. C.

Mr. Spencer H. Bickham, who died at Ledbury on 7th April, 1933, was born in 1840, and became a member of the Literary and Philosophical Society in 1868. He was a student of Owens College, and studied botany in Manchester under the late Mr. Lee Grindon. He was a noted botanist, and a fellow of the Linnæan Society. In his herbarium he had specimens of every British flowering plant, most of which he had collected himself. In his garden he had over a thousand specimens of plants from various parts of the world, and his famous rock garden was always a source of particular pleasure to visitors. He had a wide knowledge of astronomy, and his library held some rare and interesting books on this subject. He was also keenly interested in archæology. Before taking up residence at Ledbury Mr. Bickham was a member of a Manchester business firm, and lived at Alderly Edge, but since his removal his visits to Manchester have been rare. During his forty-two years' residence in Ledbury he was prominently identified with the town's affairs, and at the time of his death he held no fewer than seventeen public appointments. Keen, alert, regular and punctual in all his activities, he lived for his work, which he was able to continue until a few months before his death.

PROCEEDINGS.

COUNCIL MEETING, October 4th, 1932.

Mr. W. A. DEER and Mr. F. W. COPE were elected Student Associate Members of the Society for the Session 1932-33.

GENERAL MEETING, October 4th, 1932.

Professor W. L. BRAGG (*Vice-President*) in the Chair.

The following gentleman was elected an Ordinary Member of the Society :—

JOHN MEADOWS JACKSON, University Lecturer in Mathematics, of 3 Dartmouth Road, Chorlton-cum-Hardy, Manchester.

ORDINARY MEETING, October 4th, 1932.

Mr. W. JACKSON, M.Sc., read a paper on :—

"High Frequency Resistance and its Measurement."

Although it is usual to regard the subject of electrical engineering as falling into two parts, the one known as Heavy Electrical Engineering, and concerned with the applications of electricity to power purposes, and the other as Weak or Light Current Electrical Engineering, and concerned primarily with applications to electrical communications, a better subdivision, from the point of view of measurements, is in terms of the frequency rather than the magnitude of the currents concerned, since the characteristics of electrical networks and the technique of measurement are more a function of the former than of the latter. Thus, while there is a broad similarity, the methods adopted and the type of instrument and equipment called for in measurements at power frequency 50 cycles per second, are very different from those needed at

telephonic or audio frequencies 200-10,000 cycles per second, and more different still from those at radio frequencies of the order of 10^6 cycles per second. The rapid progress in radio communication has led to an equally rapid development in the technique of high-frequency measurements, while the attention now being devoted to the possibility of reliable long distance communication at ultra short wavelengths, that is, at frequencies approaching 10^{10} cycles per second, is likely to call for the development of again another technique of measurement, as yet sensibly unexplored.

The resistance of a circuit carrying high-frequency currents expresses in a simple manner the losses associated with the circuit during current flow, and is of vital importance in governing the performance of radio communication circuits operated in the resonant state. These losses increase rapidly with increase in frequency and fall under the heads of eddy current loss in the circuit conductors and adjacent metallic material, dielectric loss in the circuit insulation and in adjacent insulating material, and loss by energy radiation. While they do not lend themselves to independent experimental analysis, they can be measured indirectly by measurement and separation of the high frequency circuit resistance for which they can individually be regarded as responsible.

Mr. W. ANDERSON, B.Sc., and Dr. H. LOWERY gave a

"Stroboscopic Demonstration of Over-Tones."

GENERAL MEETING, October 18th, 1932.

Mr. B. MOUAT JONES (*President*), in the Chair.

The following gentlemen were elected Ordinary Members of the Society :—

WILLIAM GOOD, Research Physicist, of The Chloride Electrical Storage Co., Ltd., Clifton Junction, near Manchester.

STEPHEN ROBERT NOCKOLDS, Assistant Lecturer in Geology, of The University, Manchester.

JOHN SYDNEY HIGGINSON, Cotton Merchant, of Westfield, Anson Road, Victoria Park, Manchester.

ORDINARY MEETING, October 18th, 1932.

Mr. B. MOUAT JONES (*President*), in the Chair.

Mr. S. M. NEALE, M.Sc., delivered a report on :—

"The Faraday Society meeting on the Colloid Chemistry of Textile Fibres."

During recent years great progress has been made in elucidating the structure of solid bodies by means of X-rays. A very close connection has been found between the structure of the individual molecules and the form and mechanical properties of larger masses of the substance. It has been shown that fibres are built up from chain-like molecules of unknown length, a conclusion which had already been arrived at from a consideration of the chemical and physical properties. In fibres the atoms are bound together very firmly in a lengthwise direction, relatively loosely in a crosswise direction. At the Faraday meeting various attempts to determine the length of the molecular chains and the extent or manner of their association into groups, were described. It was agreed that the molecular chains of cellulose were built up of at least 600 sugar molecules in line. Transversely they associate into groups or bundles, the boundaries between which are ill-defined.

ORDINARY MEETING, November 1st, 1932.

Mr. B. MOUAT JONES (*President*), in the Chair.

Dr. S. R. NOCKOLDS read a paper on

"The Contaminated 'Granites' of Loch Awe, Scotland."

A calc tanalite, representing a tongue from the main Cruachan granite mass, has enclosed a large number of sedementary xenoliths near its southern margin. These have contaminated the igneous rock and it is possible to recognise three main types of contaminated "granite," their different compositions depending largely on differences in the sedimentary xenoliths which they enclose. These xenoliths, and the contaminated "granites" were described in detail, and some attention was paid to the changes which took place in the magma and in the xenoliths themselves.

ORDINARY MEETING, November 15th, 1932.

Mr. B. MOUAT JONES (*President*), in the Chair.

Mr. M. G. EVANS, M.Sc., read a paper on :—

"Modern Views of Chemical Reaction."

Simple reactions of the type Na + H . Hal were discussed on the basis of the collision theory, and explanations were advanced for the deviations of the observed velocities from those calculated on the collision basis.

Bimolecular reactions involving an activation energy were discussed by the help of energy surfaces, and the energy changes were followed as an atom approached a molecule.

Theories of unimolecular decomposition were considered and also the probability of a molecule spontaneously decomposing, first by means of vibrations throughout the molecule, and, secondly, by means of a non-radiationless transfer across a potential energy barrier.

ORDINARY MEETING, November 29th, 1932.

Mr. B. MOUAT JONES (*President*), in the Chair.

The following paper was read in title :—

"The New Mounting of the large Rowland Concave Grating at the Physical Laboratories, Manchester University."

By W. LOCHTE-HOLTGREVEN.

Professor T. B. L. WEBSTER, M.A., read a paper on :—

"Greek Vases in the Manchester Museum."

This paper is printed in the MEMOIRS.

"YOUNG PEOPLE'S MEETING," January 3rd, 1933.

The Thirteenth "YOUNG PEOPLE'S MEETING" was held at 3.30 p.m., when the following short illustrated addresses were given :—

"Art and Artists in Prehistoric Europe."

By Mrs. M. C. WRIGHT, A.R.C.Sc. (Ireland).

"How Animals Feed, and what they Eat."

By Professor H. GRAHAM CANNON, M.A., Sc.D.

During the afternoon the guests were entertained to tea in the Common Room.

GENERAL MEETING, December 13th, 1932.

Mr. B. MOUAT JONES (*President*), in the Chair.

The following gentleman was elected an Ordinary Member of the Society :—

PERCY FIELD CROSLAND, B.Sc., Chemist, *The Lea*, Walmersley, Bury.

ORDINARY MEETING, December 13th, 1932.

Mr. B. MOUAT JONES (*President*), in the Chair.

Sir ERNEST D. SIMON, M.A., read a paper on :—

"Can Education Save Democracy ?"

Something has happened to modern civilisation, and nobody knows quite why it has gone wrong. After years of scientific development science and applied science have revolutionised civilisation and removed from humanity the burden of heavy labour as it used to exist, but in spite of this, instead of living lives of comfort and leisure, we are faced with the problems of unemployment and over-production. The reason for the failure of politics, where science has had such great successes, is that science has fearlessly and without prejudice used the powers of reason which alone differentiate us from the animal world, whereas in politics scientific thinking cannot be found. There are many politicians who have boasted that they had no use for reason, and did not believe in it.

The only way to provide a solution to present problems is by scientific thought, and the application of reason to politics.

Research into economic and political affairs on lines equally scientific as those applied to physics is essential. It is almost true to say that there is no research of this kind in this country at the present time.

In the cotton trade, in spite of the seriousness of the situation, only three serious attempts at rationalisation have been made. There is an insufficiency of hard thinking.

To make a success of democracy it is essential to have educated voters to select the right kind of representatives. Education must teach us to think straight and to recognise our prejudices. A tradition of reason must be built up and made fashionable in this country.

ORDINARY MEETING, January 17th, 1933.

Mr. B. MOUAT JONES (*President*), in the Chair.

Professor J. L. STOCKS read a paper on :—

"Impressions of a visit to Russia."

After a general description of his visit to Russia, route, cost, length of stay, institutions etc. visited, the lecturer went on to discuss certain general aspects of the Bolshevik régime. First, the planned economy, the resulting sense that something was being achieved; and though the achievement might be costly, it was likely to be worth while. If they were going short of food, etc., at present, the cause was not ill-will or profiteering. Had any other nation the conviction that it had achieved anything in the last five years? Secondly, the educational effort—promising and successful in many ways, but somewhat overshadowed by (1) the tyranny of Marxist doctrine, (2) the pressure directing all intellectual effort into immediately, productive channels. This "technocratization" of intellect might, he thought, have the effect of depressing the status and energy of the brain-worker, especially when conjoined with the attempt to convince the skilled artisan that he was the most favoured class of citizen. Thirdly, the absence of political freedom and the effective denial of the democratic principle. Economic freedom, he suggested, was rather greater than one might have supposed likely; but the citizens were not encouraged to contribute constructively to the Government of the country—only to assist the Government in making its policy

effective. In this connection he discussed the withdrawal of the vodka prohibition, and the mass persecution of "Kulaks" encouraged by the agents of Government. The lecturer suggested that what the world needed was the combination of socialist economics with liberal politics.

EXTRAORDINARY GENERAL MEETING, January 24th, 1933.

Mr. B. MOUAT JONES (*President*), in the Chair.

1. Mr. Stromeyer moved "That the Council be instructed by the General Meeting to adhere to the Memorandum of Association." It was moved by Dr. Pickard, and seconded by Mr. Ritchie, that the motion be amended to read "That the Society, in General Meeting, records its confidence in the Council." The amendment was passed, and the motion so amended was carried.

2. Dr. Pickard moved that the Articles of Association of the Society be amended in accordance with the draft circulated. This motion, with certain amendments, which were accepted by the President and proposer, was duly seconded and carried by a three-fourths majority of the meeting.

3. Mr. Stromeyer's resolution to amend Article 64, being inapplicable in view of the adoption of the previous resolution, was not proceeded with.

4. At the request of the President, Mr. Stromeyer withdrew his proposal for the amendment of Articles 20-27, in order that the principles involved might be discussed by the Council before being presented to a General Meeting.

5. The subject matter of Mr. Stromeyer's resolution relating to Council Standing Orders and Nomination Lists, was referred to the Council for consideration.

ORDINARY MEETING, January 31st, 1933.

Mr. B. MOUAT JONES (*President*), in the Chair.

The President referred to the death of Mr. T. A. Coward, a member of the Society, and President from 1921 to 1923. A vote of sympathy was passed by the Society, the members standing.

Dr. W. LOCHTE–HOLTGREVEN lectured on the subject of :—

"The New Mounting of the Rowland Concave Grating in the Physical Laboratories of Manchester University."

This paper is printed in the MEMOIRS.

EXTRAORDINARY GENERAL MEETING, February 14th, 1933.

Mr. B. MOUAT JONES (*President*), in the Chair.

1. After some discussion the meeting confirmed the Resolution passed at the Extraordinary General Meeting, held on January 24th, 1933. This Resolution so became a Special Resolution of the Society.

2. Mrs. C. Walmsley and Mr. L. M. Angus-Butterworth were appointed Honorary Auditors of the Society's accounts for the Session 1932-33.

3. The following Resolution was passed :—

"That this Meeting agrees that the post of Librarian may, for the coming Session, be held by an Honorary Member of the Society."

ORDINARY MEETING, February 14th, 1933.

Mr. B. MOUAT JONES (*President*), in the Chair.

Mr. R. STUART PILCHER, F.R.S.E., M.Inst.T., read a paper on :

"Some Transport Problems."

Transport may be described as one of the essential movements in the production of wealth.

Methods of transport are changing, but whatever the type, it must be swift, comfortable, reliable, and cheap. The advent of motor vehicles has had a very great effect upon road passenger services, the first having been on tramway undertakings running into rural districts, where buses are gradually replacing tramways. In many of the smaller towns also, tramway systems have been abandoned in favour of railless traction or buses.

High compression ignition engines can be fitted to the standard chassis of a bus, and are interchangeable with the ordinary petrol engine. The same gear control and gear box

are used, but the back axle ratio is 5·75 : 1 compared with 6·25 : 1 for the petrol vehicle. The technique of driving an oil engine bus is rather different from that of a petrol bus, but the drivers have adapted themselves very rapidly to the new conditions. Owing to the good pulling power of the oil engine at low speeds it is possible to remain in top gear until a very low road speed is reached, and then to pick up speed again without changing down. This means less wear and tear on the transmission system of the bus. As the maximum speed is governed and cannot be exceeded, and as the high compression engine has a breaking effect, the wear on the brakes is greatly reduced.

Excessive fuel injection gives rise to black fumes consisting of minute particles of carbon. Leakage of lubricating oil past the piston rings into the cylinders results in the emission of a blue-grey exhaust smoke. When both types of smoke are emitted together, a very opaque mixture is formed which tends to hang over the road for some time.

The oil engine fumes, although they have an unusual smell, are absolutely innocuous, carbon monoxide being entirely absent owing to the fact that the solid fuel itself burns, without first becoming vaporised.

GENERAL MEETING, February 28th, 1933.

Mr. B. MOUAT JONES (*President*), in the Chair.

The following gentleman was elected an Ordinary Member of the Society :—

Dr. WALTER LOCHTE–HOLTGREVEN, Physicist, The University, Manchester.

ORDINARY MEETING, February 28th, 1933.

Mr. B. MOUAT JONES (*President*), in the Chair.

Mr. C. L. Barnes showed a remarkably perfect neolithic axe-head, one of a large collection bequeathed to the Manchester Museum by the late Sir W. Boyd-Dawkins. Apart from its great archæological interest, the stone has a physical property not generally known. When placed either way up on a sheet of glass it will spin easily and quietly in a counter clockwise direction, but begins to rattle immediately if spun clockwise,

unless the motion is very slow. This is because the surface on which it rests is not spherical but has an irregular curvature, and a slight want of symmetry in the stone causes it to rest on different points as it revolves. Oscillations are thus set up which resist the clockwise movement, and are rapidly magnified, but in the other direction they are smoothed out, and the motion is regular. This property is possessed by all specimens of the kind, but the direction of easy rotation may vary according to circumstances.

Mr. A. D. Ritchie drew attention to certain animals which can stand sudden changes of osmotic pressure, without special gills or water-tight skins.

Dr. Ashworth described an air pump which had been given to the Society, and which is believed to have been used by John Dalton.

Mr. Angus-Butterworth described the Saxon Sarcophagus in the church at Wirksworth, Derbyshire. This has upon it two lines of carving, which represent scenes from the latter part of the life of Christ. The placing of the scenes in a double line is common to many of the existing contemporary sarcophagi in Rome and the South of France. The slab, which is in a state of excellent preservation, was discovered during the course of extensive restoration work at the church in 1821.

Dr. Wright gave a comparison of British and Russian fossil successions.

SPECIAL MEETING, March 14th, 1933.

Mr. B. MOUAT JONES (*President*), in the Chair.

Professor T. H. PEAR, in the absence, through illness, of Dr. C. S. MYERS, read the Joule Memorial Lecture on :—

"The Psychology of Musical Appreciation."

By CHARLES S. MYERS, C.B.E., F.R.S.

This lecture is printed in the MEMOIRS.

EXTRAORDINARY GENERAL MEETING, April 25th, 1933.

Mr. B. MOUAT JONES (*President*), in the Chair.

The Hon. Secretary (Mr. D. C. Henry) moved that the Articles of Association, as set out in the notice circulated on

April 3rd, 1933, be adopted, and this proposal was duly carried by a three-fourths majority of the meeting.

GENERAL MEETING, April 25th, 1933.

Mr. B. MOUAT JONES (*President*), in the Chair.

The Annual Report of the Council and the Statement of Accounts were presented, and it was resolved :—

"That the Annual Report, together with the Statement of Accounts, be adopted, and that they be printed in the Society's PROCEEDINGS."

A vote of thanks to the Auditors, Mrs. Walmsley and Mr. Angus-Butterworth, was passed.

The following members were elected officers of the Society and Members of the Council for the ensuing year :—

President. JOHN ALLAN, F.C.S.

Vice-Presidents. W. L. Bragg, O.B.E., M.A., F.R.S. ; B. Mouat Jones, D.S.O., M.A. ; R. H. Pickard, D.Sc., F.R.S. ; C. E. Stromeyer, O.B.E., M.Inst.C.E.

Hon. Secretaries. D. C. Henry, M.A. ; W. B. Wright, Sc.D., F.G.S.

Hon. Treasurer. R. H. Clayton, B.Sc.

Hon. Librarians. C. L. Barnes, M.A. ; E. C. S. Dickson, B.A., Ph.D.

Hon. Curator. J. R. Ashworth, D.Sc.

Other Members of the Council. G. N. Burkhardt, M.Sc., Ph.D. ; G. H. Carpenter, D.Sc. ; J. D. Chorlton, M.Sc. ; H. J. Fleure, D.Sc. ; R. W. James, M.A., B.Sc. ; P. Guthlac Jones ; J. H. Mandelberg, M.A., F.I.C. ; A. M. Ranft ; A. D. Ritchie, M.A.

ORDINARY MEETING, April 25th, 1933.

Mr. B. MOUAT JONES (*President*), in the Chair.

Mr. C. D. HENRY, M.A., gave

"A Practical Demonstration of the Acoustic Properties of Musical Notes."

GENERAL MEETING, May 9th, 1933.

Mr. B. MOUAT JONES (*Vice-President*), in the Chair.

The following gentleman was elected as an Ordinary Member of the Society :—

ALEXANDER WILLIAM GORDON EWING, D.Sc., Assistant Lecturer in the Victoria University of Manchester.

ORDINARY MEETING, May 9th, 1933.

Mr. B. MOUAT JONES (*Vice-President*), in the Chair.

The following papers read were :—

"A Redescription of the known British Silurian Species of Calymene (*s.l.*)"

By J. SHIRLEY, M.Sc.

(In title only).

This paper is printed in the MEMOIRS.

"An Approximate Wave Function for the Normal Helium Atom."

By D. R. HARTREE, M.A., Ph.D., F.R.S., and A. L. INGMAN, B.Sc.

(In title only).

This paper is printed in the MEMOIRS.

"A Practical Method for the Numerical Integration of Differential Equations."

By D. R. HARTREE, M.A., Ph.D., F.R.S.

(In title only.)

This paper is printed in the MEMOIRS.

"On the Use of Chromosomes in Placing the Evolution of a Species."

By IRENE MANTON, Ph.D.

CHEMICAL SECTION.

ORDINARY MEETING, FRIDAY, OCTOBER 28th, 1932.

Dr. R. GUELKE, introduced a discussion on :—

"A New Photo-Electric Photometer and its Applications."

A Joint Meeting of the Society with the Manchester Sections of the Society of Dyers and Colourists, the Society of Chemical Industry, and the Institute of Chemistry, was held on November 10th, 1932.

Professor A. FINDLAY, M.A. (Aber.), Ph.D. (Leipzig), read a paper on :—

"Science and the Community."

ORDINARY MEETING, FRIDAY, NOVEMBER 26th, 1932.

Dr. F. G. FENELON, M.A., introduced a discussion on :—

"Works Transport."

JOINT MEETING WITH THE MANCHESTER SECTION OF THE SOCIETY OF DYERS AND COLOURISTS, FRIDAY, DECEMBER 16th, 1932.

Mr. S. M. NEALE, M.Sc., read a paper on :—

"Recent Investigations into the Behaviour of Direct Cotton Dyestuffs."

ORDINARY MEETING, FRIDAY, JANUARY 27th, 1933.

Mr. F. W. BAILEY introduced a discussion on :—

"The Bi-Sulphite Wood Pulp Process."

ORDINARY MEETING, FRIDAY, FEBRUARY 24th, 1933.

Mr. L. M. ANGUS–BUTTERWORTH introduced a discussion on

"Processes of Glass Manufacture."

ANNUAL GENERAL MEETING, MARCH 31st, 1933.

The following members were elected Officers and Members of the Committee of the Section for the year 1933-34 :—

Chairman. L. M. Angus-Butterworth, F.R.G.S., F.S.A.

Vice-Chairman. A. Gill, B.Sc., A.I.C.

Secretary. David M. Paul, B.Sc., A.I.C.

Committee. H. Cheetham, Fel. C.I.P.A. ; M. F. S. Choate ; J. R. Hannay ; H. Hayhurst ; R. Humphreys, A.I.C. ; E. N. Marchant ; T. D. Morgan ; C. W. Soutar, M.A., Ph.D. ; H. Stevenson, F.I.C.

ORDINARY MEETING, MARCH 31st, 1933.

Dr. D. Burton, M.B.E., introduced a discussion on :—

"The Art and Science of Leather Manufacture."

ANNUAL REPORT OF THE COUNCIL, APRIL, 1933.

Membership.

During the session seven new members have been elected, and two ordinary members (Mr. T. A. Coward and Dr. J. Thomas), have died. Five members have been removed from the list of members. To March 31st, 1933, there are 207 ordinary members of the Society, including five life members, and one honorary member who, at his own request, has reverted to the category of ordinary members.

Student Associates.

During the session the Council has elected two student associate members.

Meetings.

During the year April 1st, 1932, to March 31st, 1933, fourteen papers have been read before the Society, and at the meeting held on February 28th, short communications were made by members.

Six meetings and a Soireé have been held by the Chemical Section, one being a combined meeting with the Manchester Section of the Society of Dyers and Colourists, when a paper on " Recent Investigations into the Behaviour of Direct Cotton Dyestuffs " was read by Mr. S. M. Neale, M.Sc.

A joint meeting with other Manchester Chemical Societies was held at the Textile Institute on November 10th, when Professor A. Findlay lectured on " Science and the Community."

Society's Accounts.

An audited report of the Society's cash account is attached to this report, together with a statement of assets and liabilities. £200 of the balance of the Building Fund has been invested in Funding Loan 4 per cent. stock.

Society's Library.

The total number of volumes catalogued to date is approximately 46,155; the additions to the library amounting to 740 volumes, 733 serials and 7 separate works.

Gifts have been received from Mr. Stromeyer, Mr. Angus-Butterworth and others.

Volume 76 of the *Memoirs and Proceedings* (1931-32), has been published during the year, and new exchanges have been arranged with the following:

The Academy of Science, Allahabad.
The Geological Society of China.

Gifts.

Portraits of Mr. C. E. Stromeyer and Mr. C. L. Barnes, by Mr. D. P. G. Andrew, have been presented to the Society by Dr. W. B. Wright; and Mr. Barnes has given four portraits.

The Council has accepted the gift of an air-pump, believed to have been used by John Dalton, from Mr. A. McCandlish.

Chemical Section.

At the Annual General Meeting of the Section, the following officers were elected:—

Chairman: Mr. L. M. Angus-Butterworth; *Vice-Chairman:* Mr. A. Gill; *Secretary:* Mr. D. M. Paul.

At March 31st the Section had a membership of 79.

The following subjects have been discussed at meetings during the year:—

"A new Photo-Electric Photometer and its Applications" (Dr. R. Guelke); "Works Transport" (Dr. F. G. Fenelon); "The Bi-Sulphite Wood Pulp Process" (Mr. F. W. Bailey); "Processes of Glass Manufacture" (Mr. L. M. Angus-Butterworth); "The Art and Science of Leather Manufacture" (Dr. D. Burton).

Visiting Societies.

The following Societies have held meetings in the Society's rooms: The Manchester Astronomical Society; The Institution of Civil Engineers (Manchester Association); The Manchester Microscopical Society; The Manchester Statistical Society;

The Society of Dyers and Colourists (Manchester Section); The Institution of Locomotive Engineers (Manchester Centre): The Ancient Monuments Society, and the Biological Association.

Committees.

The Council appointed the following Committees :—

House and Finance.

Dr. Carpenter and Mr. Thorp.

Wilde Endowment.

Dr. Carpenter and Dr. Pickard.

Publications.

Mr. James, Professor Lapworth, Dr. Carpenter and Mr. Ritchie.

Library and Apparatus.

Dr. Ashworth, Professor Bragg and Dr. Pickard.

New Premises.

Mr. James, Dr. Levinstein, and Mr. Thorp.

The President, Secretaries, Treasurer and Librarians are *ex-officio* members of the above Committees.

Chemical Section:

Miss Alexander, Mr. Allpass, Mr. Angus-Butterworth, Mr. Choate, Mr. Gill, Mr. Hannay, Mr. Humphries, Mr. Marchant, Mr. Morgan, Mr. Paul, Dr. Soutar, and Mr. Terleski.

MANCHESTER LITERARY

Dr. *R. H. Clayton, Treasurer, in Account with the*

GENERAL

	£	s.	d.	£	s.	d.
To Balance in Treasurer's Hands, 1st April, 1932				29	10	10½
To Members' Subscriptions :—						
Half Rate 1931-32, 2 at £1 1s. 0d.	2	2	0			
,, 1932-33, 9 ,, ,,	9	9	0			
Full Rate 1929-30, 3 ,, £2 2s. 0d.	6	6	0			
,, 1930-31, 7 ,, ,,	14	14	0			
,, 1931-32, 32 ,, ,,	67	4	0			
,, 1932-33, 151 ,, ,,	317	2	0			
,, 1933-34, 2 ,, ,,	4	4	0			
Student Associates 1932-33, 2 ,, 5s.	0	10	0			
Part Life Composition Fee	25	0	0			
				446	11	0
To Sale of Publications				13	15	2
To Dividends :—						
Natural History Fund	45	18	8			
Joule Memorial Fund	13	3	9			
Wilde Memorial Fund	1	17	6			
General Fund	3	15	0			
				64	14	11
To Bonus on War Loan Conversion				3	15	0
To Transfer from Wilde Endowment Fund . .				182	7	10
To Receipts from Visiting Societies for Expenses of Meetings :—						
Manchester Astronomical Society . . .	6	0	0			
,, Statistical Society	10	0	0			
,, Microscopical Society . . .	15	0	0			
,, Inst. of Locomotive Engineers .	12	12	0			
Society of Dyers and Colourists (Manchester Section)	5	0	0			
Ancient Monuments Society	8	0	0			
Biological Association	2	10	0			
				59	2	0
To Returned Income Tax				126	9	4
To Sale of Old Carpet				4	19	0
To Refund on Insurance Premiums . . .				2	5	0
To Overdraft at Bank				773	18	8
				£1707	8	9½

AND PHILOSOPHICAL SOCIETY.

Society, from 1st April, 1932, to 31st March, 1933. **Cr.**

FUND.

	£	s.	d.	£	s.	d.
By Overdraft at Bank, 1st April, 1932 . .				492	4	4
By Charges on Property :—						
Chief Rent	9	13	10			
Insurance against Fire	15	0	0			
Income Tax	3	4	6			
				27	18	4
By House Expenditure :—						
Coal, Gas, Electric Light, Water, etc. . . .	68	4	2			
Tea, Coffee, etc., at Meetings	11	2	5			
Cleaning, etc.	8	14	5			
Replacements	72	1	10			
Repairs, etc.	6	5	10			
				166	8	8
By Administrative Charges :—						
Caretaker and Housekeeper	129	3	9			
Extra attendance at Meetings	2	11	6			
Insurance against Liability	0	19	5			
Postages, Carriage of Parcels	28	14	5½			
Stationery	17	13	11			
Bank Charges	3	8	9			
Share of Expenses of Joint Meeting . .	1	14	0			
Share of Expenses of Joint Advisory Committee of Chemical Societies	7	0	0			
National Health Insurance Stamps . .	10	3	8			
Young People's Meeting Expenses . .	10	2	4½			
Miscellaneous Expenses	15	10	9			
				227	2	7
By Printing "Memoirs and Proceedings," Circulars, etc. .				197	8	5
By Periodicals (except those charged to Natural History Fund)				133	9	8
By Natural History Fund :— (Items shown in Balance Sheet of this Fund) . .				20	11	0
By Post Office Telephone				12	1	0
By Transferred to Wilde Endowment Fund				338	16	3
By Bookbinding				64	6	3
By Restoring Society's Pictures				10	2	0
By Subscription to Lancashire & Cheshire Fauna Committee				1	1	0
By Cash in Treasurer's Hands				15	19	3½
				£1707	8	9½

WILDE ENDOWMENT FUND, 1932-33.

Dr. Cr.

Dr.	£	s.	d.
To Balance at Bank, 1st April, 1932	620	12	3
To Dividend on £7500 Gas Light and Coke Company's Ordinary Stock	315	0	0
To Interest on £50 5 per cent. War Loan Stock	1	17	6
To Refunded Income Tax 1929-30, 1930-31, 1931-32	286	18	9
To Part Assistant Secretary's salary refunded from General Fund	50	0	0
To Bank Interest	3	8	0
	£1277	16	6

Cr.				£	s.	d.
By Assistant Secretary's Salary				200	0	0
By Repayment to Building Fund—Payment for decorations charged in error				338	9	0
By Bookbinding (Refund to General Fund)				25	0	0
By Repairs and Replacements (Refund to General Fund)				71	0	10
By Restoring Society's Pictures („ „ „)				10	2	0
By Transferred to General Fund—						
13 Subscriptions at £1 1s. od.	£13	13	0			
Entrance Fees	12	12	0			
In lieu of Rent	50	0	0			
				76	5	0
By Repairs and Replacements				8	12	10
By Bank charges				0	4	2
By Balance at 1st April, 1933				548	2	8
				£1277	16	6

BUILDING FUND, 1932-33.

	£	s.	d.
To Balance at Bank, 1st April, 1932	246	13	5
To Rents	59	17	5
To Interest on £700 Funding Loan 4 per cent. Stock	24	0	0
To Refund from Wilde Fund—Decorations charged in error 1919-21	338	9	0
To Bank Interest	0	19	11
	£669	19	9

	£	s.	d.
By Purchase of £200 Funding Loan 4% Stock	195	1	0
By Balance at 1st April, 1933	474	18	9
	£669	19	9

JOULE MEMORIAL FUND, 1932-33. (Included in the General Account, above.)

	£	s.	d.
To Dividend on £100 East India Railway Company's 4½ per cent. Annuity Class A Stock	3	16	3
To Interest on £250 5 per cent. War Loan Stock	9	7	6
	£13	3	9

	£	s.	d.
By Balance Transferred to the General Fund	13	3	9
	£13	3	9

NATURAL HISTORY FUND, 1932-33. (Included in the General Account, above.)

Dr. Cr.

	£	s.	d.
To Dividend on £1225 Great Western Railway Company's Stock	45	18	8
	£45	18	8

	£	s.	d.
By Natural History Periodicals	18	16	0
By Subscriptions :—			
North Western Naturalists' Union 1932	0	14	0
Ray Society, 1933	1	1	0
By Balance Transferred to General Fund	25	7	8
	£45	18	8

STATEMENT RELATING TO THE SOCIETY'S PROPERTY AS ON 31st MARCH, 1933.

LIABILITIES.	£	s.	d.
Printing :—			
In the Press. Vol. 77 (approximately)	150	0	0
Binding	75	0	0
Overdraft at Bank (General Fund)	773	18	8
	£998	18	8

ASSETS.	£	s.	d.
Arrears of Subscriptions, 1932-33 (estimated to produce)	56	14	0
Arrears of Subscriptions, earlier (estimated to produce)	42	0	0
Income Tax (recoverable) April 1st, 1931—March 31st, 1932	120	0	0
Rents to Lady Day, 1932	15	10	0
Expenses of Meetings	33	11	0
Cash Balance :—			
In Bank, Building Fund	474	18	9
„ Wilde Endowment Fund	548	2	8
	£1290	16	5
Investments :—			
£7500 Gas Light and Coke Company's Ordinary Stock (W.E.F.)			
£1225 Great Western Railway Company's 5 per cent. Consolidated Preference Stock (Nat. Hist. F.)			
£100 East India Railway Company's 4½ per cent. Annuity Class A (J.M.F.)			
£250 5 per cent. War Loan Stock, 1929-47 (J.M.F.)			
£50 „ „ „ „ (W.E.F.)			
£75 „ „ „ „ (Gen. Fund)			
£700 4 per cent. Funding Loan (Building Fund)			
Society's Premises, Furniture, Library, Collections, Stock of Unsold Publications, and New Premises, 21 and 21A Back George Street.			

There are 5 Life Composition Fees.

NOTE.—The Treasurer's Accounts of the Session 1932-33 have been endorsed as follows :—

April, 4th, 1933. Audited and found correct.

We have seen at this date, the Bankers' certificate that they hold £375 of 5 per cent. War Loan Bonds :—2 Bonds for £100 each, Nos. 71827 and 366270; 2 Bonds for £50 each, Nos. 131,577 and 31,358; 1 Bond for £50, and a Bond for £25, 5 per cent. War Loan, 1929/47 Inscribed Stock; and the Certificates of the following Stocks :—£1225 Great Western Railway Company 5 per cent. Consolidated Preference Stock, Nos. 12,293, 12,294, and 12,323 ; £7500 Gas Light and Coke Company Ordinary Stock (No. 8/1960) ; £100 East India Railway Company £4 10s. per cent. Annuity Class A Stock (No. 25,656) ; £700 4 per cent. Funding Stock, 1960-1990, Nos. 34,185 and 23/3454 ; and the deeds of the Natural History Fund, of the Wilde Endowment Fund, those conveying land on which the Society's premises stand, and the Declarations of Trust.

Leases and Conveyances dated as follows :—

22nd Sept., 1797.
23rd Sept., 1797.
25th Dec., 1799.
25th Dec., 1799.
22nd Dec., 1820.
23rd Dec., 1820.

Declarations of Trust :—

24th June, 1801.
23rd Dec., 1820.
8th Jan., 1878.

Appointment of New Trustees :—

30th April, 1851.

Conveyance relating to the property, 21 Back George Street, Manchester, dated 7th December, 1920.

We have also seen the Dalton and other Medals of the Society.

We have verified the balances of the various accounts with the banker's pass books.

(*Signed*) DORIS WALMSLEY.
L. M. ANGUS-BUTTERWORTH.

LIST OF SOCIETIES AND INSTITUTIONS.

TO WHICH THE *Memoirs and Proceedings* ARE SENT.

Societies and Institutions present their publications to the Society's Library with the exception of those marked with a dagger (†).

Aberystwyth. †National Library of Wales.
Abo. Akademie Bibliotek.
Adelaide. Royal Society of Australia. South Australian Museum.
Amsterdam. Koninklijke Akademie van Wetenschappen. Société Mathématique.
Auckland. The Auckland Institute and Museum.
Augsburg. Der naturwissenschaftlicher Verein für Schwaben.

Baltimore. Johns Hopkins University.
Bamberg. Naturforschende Gesellschaft.
Bangalore (Madras). Indian Institute of Science.
Basle. Naturforschende Gesellschaft. Helvetica Chimica Acta.
Batavia. Koninklijke Natuurkundige Vereeniging in Nederlandsch-Indië. Bataviaasch Genootschap van Kunsten en Wetenschappen.
Bath. Bath and West and South Counties Society.
Belfast. Naturalists' Field Club.
Bergen. Geofysisk Institutt.
Berkeley. University of California.
Berlin. Preussische Akademie der Wissenschaften.
Berne. Schweizerische Naturforschende Gesellschaft.
Besançon. Société d'émulation du Doubs.
Birmingham. Natural History and Philosophical Society.
Bloemfontein. National Museum.
Bologna. Reale Accademia delle Scienze dell'Istituto.
Bombay. Branch of the Royal Asiatic Society of Bengal.
Bonn. Naturhistorischer Verein der preussischen Rheinlande und Westfalens.
Bordeaux. Société des Sciences physiques et naturelles.
Boston. American Academy of Arts and Sciences. Society of Natural History.
Boulder. University of Colorado.
Bremen. Naturwissenschaftlichen Verein.

Brisbane. Queensland Museum. Royal Society of Queensland. Royal Geographical Society of Australia, Queensland Branch.
Bristol. Naturalists' Society.
Brno. Faculty of Science, Masaryk University.
Brooklyn (N. Y.). Institute of Arts and Sciences.
Brussels. Académie Royale de Belgique. Musée Royal d'Histoire Naturelle de Belgique.
Buenos Aires. Sociedad Cientifica Argentina.
Buffalo. Society of Natural Sciences.

Caen. Académie nationale des Sciences, Arts et Belles-Lettres. †Société Linnéenne de Normandie.
Calcutta. Department of Agriculture in India, Agricultural Research Institute (Pusa). Geological Survey of India. Indian Association for the Cultivation of Science. Meteorological Department of India (Poona). Royal Asiatic Society of Bengal.
Cambridge. Philosophical Society. †University Library.
Cambridge (Mass.) Harvard College. †Massachusetts Institute of Technology Library.
Cape Town. Royal Society of South Africa. South African Museum.
Cardiff. Naturalists' Society.
Catania. Accademia Gioenia di Scienze naturali.
Chambéry. Académie des Sciences, Belles-Lettres et Arts de Savoie.
Chapel Hill. Elisha Mitchell Scientific Society.
Charlottenburg. Physikalisches-Technischen Reichsanstalt.
Cherbourg. Société nationale des Sciences naturelles.
Chicago. Astrophysical Journal. Field Museum of Natural History.
Cincinnati. Lloyd Library and Museum. †American Association for the Advancement of Science. Society of Natural History.
Clermont-Ferrand. La Société des amis de l'Université de Clermont.
Colorado Springs. Colorado College Coburn Library.
Columbia. University of Missouri.
Columbus. Ohio State University.
Copenhagen. Kongeligt Danske Videnskabernes Selskab. Kongeligt Nordisk Oldskrift-Selskab. Naturhistorisk Förening.
Cracow. Société Polonaise Mathématique.
Cullercoats. See Newcastle-upon-Tyne.

Danzig. Naturforschende Gesellschaft. Westpreussischer Botanisch-Zoologischer Verein.
Davenport. Academy of Natural Sciences.
Delft. Technische Hoogeschool.
Des Moines. Iowa Geological Survey.
Dijon. Académie des Sciences, Arts et Belles-Lettres.
Dorpat. Naturforschende Gesellschaft.
Douai. Société d'Agriculture, Sciences et Arts du Départment du Nord.
Draguignan. Société d'études Scientifiques et Archéologiques.
Dublin. †National Library of Ireland. Royal Dublin Society. Royal Irish Academy. †Trinity College Library.
Dunkerque. Société Dunkerquoise pour l'encouragement des Sciences.
Durban. †Corporation Museum.

Elberfeld. Naturwissenschaftlicher Verein.
Épinal. Société d'émulation des départmentes des Vosges.
Edinburgh. Botanical Society. Geological Society. Mathematical Society. †National Library of Scotland. Royal Botanic Gardens. Royal Observatory. Royal Physical Society. Royal Society. Royal Scottish Society of Arts. †Scottish Meteorological Society.
Erlangen. Physikalisch-medizinische Societät.
Evreux. Société libre d'Agriculture, Sciences, Arts et Belles-Lettres de l'Eure.

Falmouth. Royal Cornwall Polytechnic Society.
Florence (Firenze). Biblioteca Nazionale Centrale.
Frankfurt-am-Main. Physikalischer Verein. Senckenbergische Naturforschende Gesellschaft.
Freiburg i. Br. Naturforschende Gesellschaft.

Geneva. Institute national Génévois. Société de Physique et d'Histoire Naturelle. See also Basle.
Genova. Museo Civico di Storia Naturale.
Giessen. Oberhessische Gesellschaft für Natur-und Heilkunde.
Glasgow. Geological Society. Natural History and Microscopical Society. Royal Philosophical Society. †University Library.
Görlitz. Naturforschende Gesellschaft.
Göteborg. Göteborgs Stadtsbibliotech (Högskole).
Göttingen. Gesellschaft der Wissenschaften.

Grahamstown. Albany Museum.
Granville. Denison University.
Gratz. Verein des Aertze in Steiermark.
Greenwich. Royal Observatory.

Haarlem. Hollandsche Maatschappig der Wetenschappen. Musée Teyler. Nederlandsche Maatschappig ter bevordering van Nijverheid.
Halifax, N.S. Nova Scotian Institute of Science.
Halle. Kaiserliche Akademie der Naturforscher. Naturforschende Gesellschaft und Naturwissenschaftlicher Verein.
Hamburg. Naturwissenschaftlicher Verein.
Hanley. See Stoke-on-Trent.
Hannover. Naturhistorische Gesellschaft.
Hartford (Conn.). Connecticut State Library (Geological and Natural History Survey).
Heerlen. Geologisch Bureau van het Nederlandsch Mijngebied.
Heidelberg. Bädische Sternwarte. Naturhistorisch-medizinischer Verein.
Helsingfors. Finska Vetenskaps Societeten. Societas pro Fauna et Flora Fennica.
Hermannstadt. Siebenbürgischer Verein für Naturwissenschaften.
Hobart. Royal Society of Tasmania.
Hong Kong. Royal Observatory.
Hull. †Scientific and Field Naturalists' Club. †Yorkshire Naturalists' Union.

Indianapolis. Department of Geology and Natural Resources of Indiana.
Iowa City. Iowa State University.
Ithaca. Cornell University. Agricultural Experimental Station.

Johannesburg. South African Association for the Advancement of Science.

Kazan. Imperial University. Society of Archæology.
Kiel. Kommission zur wissenschaftlicher Untersuchung der deutschen Meere in Kiel. Naturwissenschaftlicher Verein für Schleswig-Holstein.
Kiev. Society of Naturalists.
Kodaikanal. See Madras.
Königsberg i. Pr. Königliche Universitäts-Sternwarte. Königliche Physikalisch-ökonomisch Gesellschaft.
Kyoto. College of Science and Engineering, Imperial University.

La Plata. Direccion General de Estadistica de la Prov. Buenos Aires. Universidad Nacional, Facultad de Ciencias Fisico-Matematicas.

Lausanne. Société Vaudois des Sciences Naturelles.

Lawrence. Kansas University.

Leeds. Philosophical and Literary Society. Yorkshire Geological Society. Leeds Geological Association.

Leeuwarden. Friesch Genootschap, van Geschied-, Oudheid -en Taalkunde.

Leicester. Literary and Philosophical Society.

Leiden. Maatschappig der Nederlandsch Letterkunde. Rijks Geologisch—Mineralogisch Museum. Rijks Herbarium.

Leipzig. Naturforschende Gesellschaft. Fürstliche Jablonowskische Gesellschaft. Sächsische Gesellschaft der Wissenschaften.

Le Mans. Société d'Agriculture, Sciences et Arts de la Sarthe.

Lemberg. Société Scientifique de Chevtchenko.

Leningrad. Academy of Sciences of the Union of Socialist Soviet Republics.

Liége. Société Géologique de Belgique. Société Royal des Sciences.

Lille. Société des Sciences de l'Agriculture et des Arts. L'Université.

Lima, Peru. Cuerpo de Inginieros de Minas del Peru.

Lincoln, U.S.A. University of Nebraska.

Liverpool. Biological Society. Engineering Society. Geological Society. Literary and Philosophical Society.

London. British Association. British Museum (Natural History). British Museum (Library of Pure and Applied Science). Chemical Society. Faraday Society. Geological Society. Institution of Civil Engineers. Institution of Electrical Engineers. Institution of Mechanical Engineers. Linnean Society. Mathematical Society. Meteorological Office. Patent Office. Physical Society. Quekett Microscopical Society. Royal Society. Royal Astronomical Society. Royal Geographical Society. Royal Horticultural Society. Royal Institute of British Architects. Royal Institution of Great Britain. Royal Meteorological Society. Royal Society of Arts. † Subject Index to Periodicals. Zoological Society.

Lucca. Reale Accademia Lucchese di Scienze, Lettere, ed Arti.

Lund. Universitet.

Luxembourg. Institute Grand Ducal de Luxembourg.

Lwow. See Lemberg.
Lyon. Académie des Sciences. L'Université.

Madison. Wisconsin Academy of Sciences, Arts and Letters. Wisconsin Geological and Natural History Survey.
Madras. Observatory (Kodaikanal).
Madrid. Real Academia de Ciencias. Real Sociedad Matemática Española.
Manchester. Association of Engineers. †Athenæum. †Chetham's Library. †Christie Library. Conchological Society. Geographical Society. Geological Association. Microscopical Society. †Municipal College of Technology. †Reference Library. Shirley Institute. Statistical Society. Textile Institute.
Manila. Bureau of Ethnology. Bureau of Science.
Marburg. Gesellschaft zur Beförderung der gesammten Naturwissenschaften.
Marseille. Faculté des Sciences de l'Université.
Melbourne. Royal Society of Victoria.
Metz. Académie de Metz.
Mexico. Instituto Geológico. Sociedad Cientifico "Antonio Alzate."
Middleburg. Zeeuwsch Genootschap der Wetenschappen.
Milan. Reale Istituto Lombardo di Scienze e Lettere. Reale Osservatorio di Brera in Milano (Merati, Como.). Società Italiana di Scienze Naturali, e Museo Civico.
Minneapolis. University of Minnesota. †Academy of Natural Sciences.
Missoula. University of Montana.
Modena. Regia Accademia di Scienze, Lettere ed Arti.
Monte Video. Museo de Historia Natural.
Montpellier. Académie des Sciences et Lettres.
Montreal. Royal Society of Canada.
Munich. Bayerische Akademie der Wissenschaften.

Nancy. Société des Sciences de Nancy.
Naples. Accademia delle Scienze fisiche e matematiche. Accademia di Archeologia, Lettere e Belle Arti. Società Reale di Scienze.
Neuchâtel. Société neuchâteloise des Sciences naturelles.
Newcastle-upon-Tyne. Dove Marine Laboratories, Cullercoats. †Literary and Philosophical Society. Natural History Society of Northumberland, Durham, and Newcastle-upon-Tyne. University of Durham Philosophical Society.

New Haven (Conn.). Connecticut Academy of Arts and Sciences. Bingham Oceanographic Collection.

New York. Academy of Sciences. American Chemical Society. American Mathematical Society. American Museum of Natural History. Meteorological Observatory (Central Park). Vanderbilt Marine Museum.

Nîmes. Académie de Nîmes.

Norman. Oklahoma Academy of Science.

Norwich. Norfolk and Norwich Naturalists' Society.

Offenbach. Der Offenbacher Verein für Naturkunde.

Oslo. Norske Videnskaps Akademie. Norsk Meteorologisk Institut. Observatorium. Bibliothèque de l'Université Royale de Norvège.

Ottawa. Geological Survey of Canada.

Oxford. †Bodleian Library. Radcliffe Observatory. Radcliffe Library.

Palermo. Reale Accademia di Scienze, Lettere, e Belle Arti.

Paris. Académie des Sciences. École nationale supérieur des Mines. École polytechnique. Muséum d'Histoire naturelle.

Philadelphia. Academy of Natural Sciences. American Philosophical Society. Franklin Institute. †Philadelphia Commercial Museum. Wagner Free Institute of Science.

Pietermaritzburg. †Government Geologist, Surveyor General's Office. Natal Government Museum.

Plymouth. Plymouth Institution and Devon and Cornwall Natural History Society.

Portici. Laboratorio di Zoologia generale e agraria, R. Scuola sup. di Agricoltura.

Porto. Academica Polytechnica.

Prague. Königliche Böhmische Gesellschaft der Wissenschaft.

Puget Sound. See Seattle.

Pusa. See Calcutta.

Rheims. Académie nationale.

Riga. Naturforscher Verein.

Rochelle. Société des Sciences naturelles de la Charente inférieure.

Rochdale. Literary and Scientific Society.

Rochester, N.Y. Academy of Science.

Rock Island. Augustana College Library.

Rome. Institut International d'Agriculture. Reale Accademia dei Lincei. Società Italiana per il progresso delle Scienze. Vatican Observatory (Specola Vaticana).
Rostock. Verein der Freunde der Naturgeschichte in Mecklenburg.
Rouen. Académie des Sciences.

Sacramento. See Berkeley.
St. Louis. Missouri Botanical Garden. †Academy of Science. The Washington University.
St. Paul. See Minneapolis.
Salford. †Royal Museum and Library.
San Diego. Society of Natural History.
San Francisco. California Academy of Sciences.
Santiago. Deutscher Wissenschaftlicher Verein.
Sassari. Regia Università Istituto Fisiologico.
Seattle. University of Washington. Puget Sound Marine Biological Station.
Sendai. Tohoku Imperial University.
Sheffield. Midland Institute of Mining, Civil and Mechanical Engineers. Safety in Mines Research Board Laboratories.
Simla. See Calcutta.
Southport. Fernley Observatory.
Stockholm. Entomologiska Föreningen. Kongeliga Svenska Vetenskaps-Akademi. Royal Library. Sveriges Geologiska Undersökning.
Stoke-upon-Trent. North Staffordshire Field Club.
Stratford. The Essex Field Club.
Swansea. Scientific and Field Naturalists' Society.
Sydney. Australian Association for Science. Australian Museum. Linnean Society of New South Wales. Royal Society of New South Wales.

Tachkent. L'Université de l'Asie Centrale.
Taihoku. Imperial University.
Tartus. See Dorpat.
Teddington. National Physical Laboratory.
Tiflis. Geophysikalisches Observatorium Georgiens.
Tokyo. Faculty of Science, Imperial University of Tokyo. Imperial Academy. Institute of Electrical Engineers of Japan. National Research Council of Japan. Physico-Mathematical Society of Japan.
Torino. Società Meteorologica Italiana.

Toronto. Canadian Institute. University Library.
Toulouse. Académie des Sciences, Inscriptions, et Belles-Lettres.
Trondhjem. Kongelige Norske Videnskabers Selskab Museet.
Troyes. Société Académique d'Agriculture de l'Aube.
Tufts. Tufts College.
Turin. See Torino.

Uccle. L'Observatoire royal et l'Institut royal Météorologique de Belgique.
Upsala. Kongliga Universitet. Kongliga Vetenskaps-Societeten.
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Utrecht. Koninklijk Nederlandsch Meteorologisch Instituut. Provincial Utrechtsch Genootschap van Kunsten en Wetenschappen.

Venice. Reale Istituto Veneto di Scienze, Lettere, ed Arti.
Victoria, B.C. Dominion Astrophysical Observatory.
Vienna. Kaiserliche Akademie der Wissenschaften. Kaiserlich-Königliche Universitäts-Sternwarte. Kaiserlich-Königliches Naturhistorisches Hofmuseum. Kaiserlich-Königliche Zoologisch-Botanische Gesellschaft. Oesterreichische Gesellschaft für Meteorologie.

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1904. (Feb. 23.) "The Evolution of Matter as revealed by the Radio-active Elements." By FREDERICK SODDY, M.A.

1905. (Feb. 28.) "The Early History of Seed-bearing Plants, as recorded in the Carboniferous Flora." Dr. D. H. SCOTT, F.R.S.

1906. (March 20.) "Total Solar Eclipses." By Professor H. H. TURNER, D.Sc., F.R.S.

1907. (Feb. 18.) "The Structure of Metals." By Dr. J. A. EWING, F.R.S., M.Inst.C.E.

1908. (March 3.) "On the Physical Aspect of the Atomic Theory." By Professor J. LARMOR, Sec.R.S.

1909. (March 9.) "On the Influence of Moisture on Chemical Change in Gases." By Dr. H. BRERETON BAKER, F.R.S.

1910. (March 22.) "Recent Contributions to Theories regarding the Internal Structure of the Earth." By Sir THOMAS H. HOLLAND, K.C.I.E., D.Sc., F.R.S.

SPECIAL LECTURES.

1913. (March 4.) "The Plant and the Soil." By. A. D. HALL, M.A., F.R.S.

1914. (March 18.) "Crystalline Structure as revealed by X-rays." By Professor W. H. BRAGG, M.A., F.R.S.

1915. (May 4.) "The Place of Science in History." By Professor JULIUS MACLEOD, D.Sc.

DALTON LECTURE.

1931. (Mar. 17.) "Atoms and Electrons." By Sir Joseph J. Thomson, O.M., D.Sc., F.R.S.

JOULE MEMORIAL LECTURES.

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1922. (Dec. 5.) "The Rise in Motive Power and the Work of Joule." By Sir CHARLES A. PARSONS, K.C.B., M.A., D.Sc., F.R.S.

1924. (Mar. 4.) "Thermodynamics in Physiology." By A. V. HILL, O.B.E., M.A., Sc.D., F.R.S.

1928. (Mar. 20.) "Sub-Atomic Energy." By Professor A. S. EDDINGTON, M.A., D.Sc., LL.D., F.R.S.

1930. (Feb. 18.) "Science and Problems of the Times." By A. P. M. FLEMING, C.B.E., M.Sc., M.I.E.E.

1933. (Mar. 14.) "The Psychology of Musical Appreciation." By CHARLES S. MEYERS, C.B.E., F.R.S.

WILDE MEMORIAL LECTURES.

1926. (Mar. 9.) "Brains of Apes and Men." By G. ELLIOT SMITH, M.A., M.D., F.R.S.

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1929. (Mar. 19.) "The Nature and Origin of Human Speech." By Sir RICHARD PAGET, Bart.

1932. (Mar. 15.) "Man's Place in Nature as shown by Fossils." By Sir ARTHUR SMITH-WOODWARD, LL.D., F.R.S.

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do.	EMIL WARBURG.
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Apr. 28th, 1903.	FRANK WIGGLESWORTH CLARK.

*Died May 16th, 1925.

Date of Election.	
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do.	SIR ARTHUR SCHUSTER.
do.	G. ELLIOT SMITH.
Nov. 28th, 1922.	NIELS BOHR.
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This list is in conformity with the records of the Society, but members would perform a service in notifying any changes to the Assistant Secretary.

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MEMOIRS AND PROCEEDINGS

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Memoirs.

CONTENTS.

NOTE.

THE authors of the several papers contained in this volume are themselves accountable for all the statements and reasonings which they have offered. In these particulars the Society must not be considered as in any way responsible.

I.—Greek Vases in the Manchester School of Art.

By T. B. L. Webster.

Last year I lamented that the material in the Manchester Museum gave no adequate picture of Greek vase painting at its best, the Attic black-figure and red-figure style. The vases in the School of Art, which I am permitted to publish by the kindness of the Art Gallery Committee, do something to fill the gap. I start with a black-figured cup [1] (Aa 17). It belongs to a large class which are known as little-master cups. They tell us little about contemporary painting, the field of the picture is too small, but as decorative vase painting they have no superior. They were made in the third quarter of the sixth century, B.C., at the same time as Exekias and Amasis were painting large vases. There are two main types of these cups, band cups where the decoration is confined to a reserved band between the handles, and lip cups where the offset lip is also reserved and can be decorated; we may compare the difference in decoration between the contemporary amphoræ and neck amphoræ. Our cup is a band cup: the shape is the same as that of a cup [2] in the Manchester Museum which belongs to a class known as Cassel cups. There is no picture inside, only a small reserved circle and on it a black circle, with a smaller circle round a dot inside it. Outside the reserved band is decorated in the same way on both sides of the cup, ram to right, swan to left, ram to right, swan to left, ram to left: it is perfectly satisfying; if the third ram also went to the right, the cup would revolve, for the rams

[1] Herford, *Handbook of Greek Vase Painting*, pl. 6*b*. I am indebted to Miss Herford (Mrs. Braunholtz) for the photographs reproduced in Figs. 2 and 5.

[2] *Manchester Memoirs*, lxxvii, pl. 1, 2 (left); see Beazley, *J.H.S.*, 1933, p. 191.

would be too heavy for the swans: therefore the last ram goes to the left, balancing his fellows. The cup is made cheerful and gay by the added red on the rams' necks and flanks and by the added white on the rams' horns and bodies. A lip cup in the Louvre [1] has a single ram in the top band, with red on his neck and flank and white on his horns and sides; the drawing of horn, shoulder, ribs and flank is exactly the same as in our ram. The likeness is so great that we may confidently ascribe our cup to the same painter and probably to the same potter. The Louvre cup is signed in the lower band "Tleson, son of Nearchos, made." The father Nearchus was also a potter; Tleson's factory went on into the early red-figured period. Many of the fifty signed little-master cups [2] from this factory seem to be by one hand; this artist also painted our cup. The goats on a signed cup in Castle Ashby [3] have the same treatment of ribs and flank and the same white spots.

The next vase (Aa 24) takes us into the red-figure period. It is a cup of the early red-figure shape with the stem terminating abruptly, where the foot starts (in later cups, such as Aa 57, the stem curves over on to the foot and the dividing line is halfway down the foot); in the earlier shape the parts are clearly defined, in the later the profile is a single flowing curve. There is no decoration except the scene in the interior (Fig. 1). There is an inscription in the field of the centre medallion, "Elpinikos is beautiful." It is one of the love inscriptions which are so common on red-figure vases. The name Elpinikos occurs on three other vases,[4] a cup in Bonn which is of the same date, a fragmentary cup in Boston and a fragment in Florence. The name is not known from any other source: the famous Athenian general, Kimon, had a sister, Elpinike. Can our Elpinikos be her brother? Kimon was born about 510 B.C. Our vase must have been painted soon after 500 B.C., which would mean that Elpinikos must have been born soon after 520 B.C.; it would then be perfectly possible for him to be

[1] F. 86, Pottier, *Album*, pl. 69.

[2] See Beazley, *J.H.S.*, 1933, p. 195.

[3] Beazley, *Attic Black Figure*, pl. 5, 1.

[4] Klein, *Lieblingsinschriften*, p. 86. Beazley ap. Caskey, *Attic Vase Paintings in Boston*, p. 6.

an elder brother of Kimon, son of Miltiades, the victor of Marathon. The young man is seated on a couch with a cloak about his legs (his feet are cut off by the frame of the picture). In his right hand he holds a cup with offset rim by the first finger: he is playing the game called *Kottabos*, in which the dregs in the bottom of the cup are flicked on to a mark. In his left hand he holds a lyre which he has been playing or is going to play. The attachments of the strings to the bar are in red; the plectrum, also in red, hangs down by a red string from the arm of the lyre. He has a red fillet round his head and his left arm goes over the corner of the cushion on which he is resting. The cushion is washed over with thin glaze like the shields on Euphronios' Amazonomachy. The outline of the hair is incised. It is a subject naturally suited to an oblong space, but the painter has adapted it to a circle by emphasising the diagonal line from the right hand through the lyre to the cushion and left elbow, and the vertical of the overhanging swag of drapery. He has also rendered the foreshortening of the left leg through the drapery: foreshortening is a problem which is beginning to exercise painters. Beazley says that all the Elpinikos cups are by the same hand. I think it is just possible that they are early works by the Eucharides painter, the shape of the head, eye, ear, the collar bones, breast bones, long thin fingers and thumbs are like his.

The other red-figured cup (Aa 57) was painted some twenty years later. Like the Elpinikos cup, it has no decoration except the scene in the interior (Fig. 2). A young man is lurching home after dinner. He is wearing boots and a large cloak; his stick has fallen from his hands. He has on his head a wreath of flowers (in red), a chaplet of leaves and a long red streamer like that on Elpinikos' head. Notice the brown inner markings, the heavy simple drapery instead of the elaborate folds of the earlier cup, the profile eye, the dynamic composition; these are all marks of a later date. The cup is very like the work of the Brygos painter: if it is not by his hand, it must be by a pupil of his. The cloak is not so plastic as his usually are, but compare the Boston kotyle.[1] The use

[1] Beazley, *V.A.*, fig. 58, Caskey, *op. cit.*, pl. vii.

of the stick to echo an important line can be seen on a London cup,[1] the wreath and chaplet on a cup in Florence,[2] the inner markings of the legs, the head with small ear, heavy chin and whisker, on his masterpiece, the Würzburg cup.[3]

The Brygos painter's pictures are full of fire and passion. But some of his contemporaries are quieter, and seem rather to embody that spirit of Sophrosyne (modesty), which we associate particularly with the Greeks. The oenochoe[4] (Aa 25) belongs to this class. The picture is a woman playing the lyre and singing: she wears the long Ionic chiton and a cloak thrown over both shoulders and falling down her back, a wreath on her head and a bracelet on her arm. It might be Sappho; the Brygos painter painted Sappho with a lyre. In our vase the singer's head is frontal. In the sixth century heads were always represented profile though the eye was frontal: the painter thought of the head as profile and the eye as frontal and therefore put them down like this. In the last quarter of the century the painter begins to want to put things down as they appear. The earliest frontal face is on a vase by Euphronios.[5] The painter of the cup which we have just been considering (about 480 B.C.) very nearly achieved a profile eye. The painter of this jug tries the much more difficult frontal face: the Brygos painter in the Sappho vase goes yet further and paints a three-quarter face. By the middle of the fifth century these things are no longer problems. A Nike (victory)[6] by the Pan painter is contemporary with our vase. She also has a frontal face and is playing the lyre. On this vase you can see also the cover or apron of the lyre, the spare strings, and the band through which the left hand passes; these details occur again on a wonderful vase by the Berlin painter.[7]

By the middle of the century the technical problems of perspective and foreshortening have been solved, as far as they can be solved in line drawing. The painter now wants to paint expressions and character. Three vases belong to

[1] Pfuhl, *M.v.Z.*, fig. 432.
[2] Pfuhl, *op. cit.*, fig. 431.
[3] Pfuhl, *op. cit.*, fig. 421-3.
[4] Herford, *op. cit.*, pl. 9*b*.
[5] Pfuhl, *op. cit.*, fig. 394.
[6] Beazley, *Panmaler*, pl. 14, 2.
[7] Beazley, *Berliner Maler*, pl. 21.

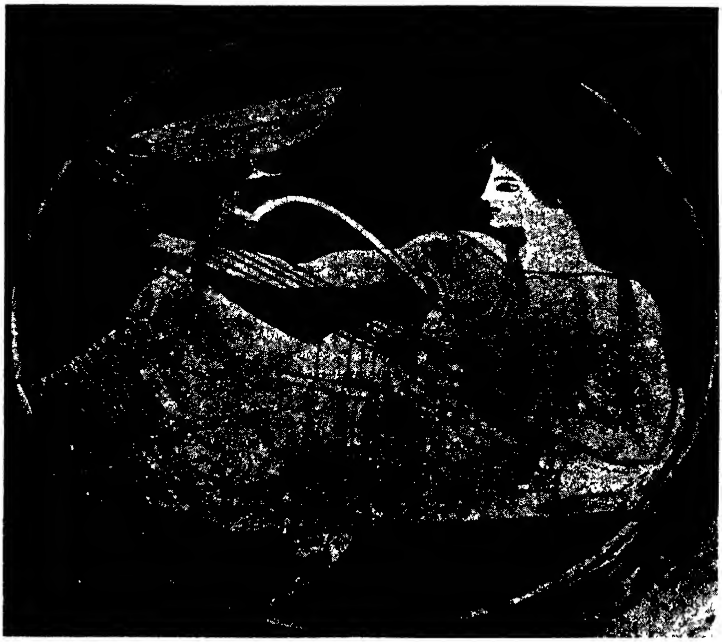

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PLATE I.

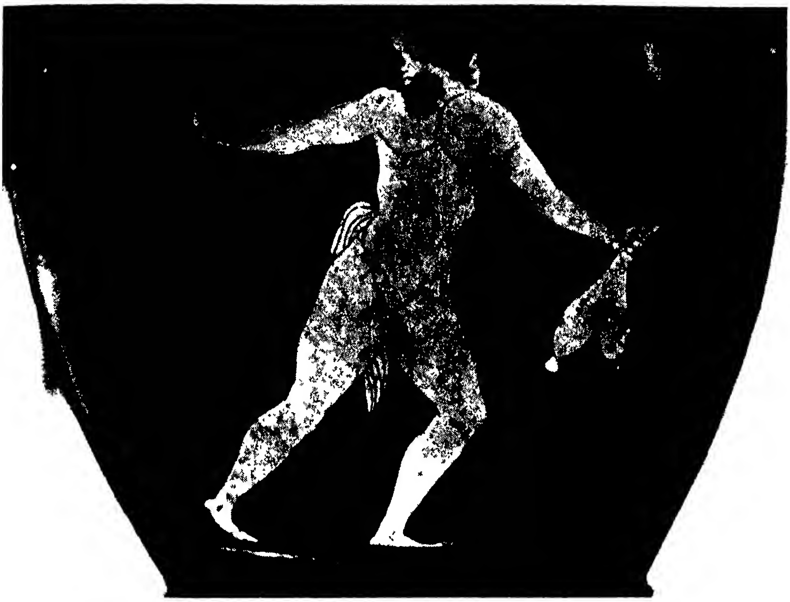

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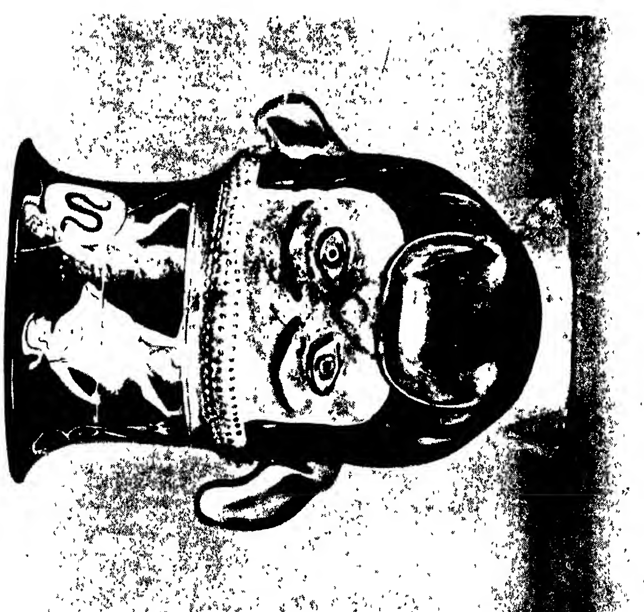
PLATE II.

PLATE III.



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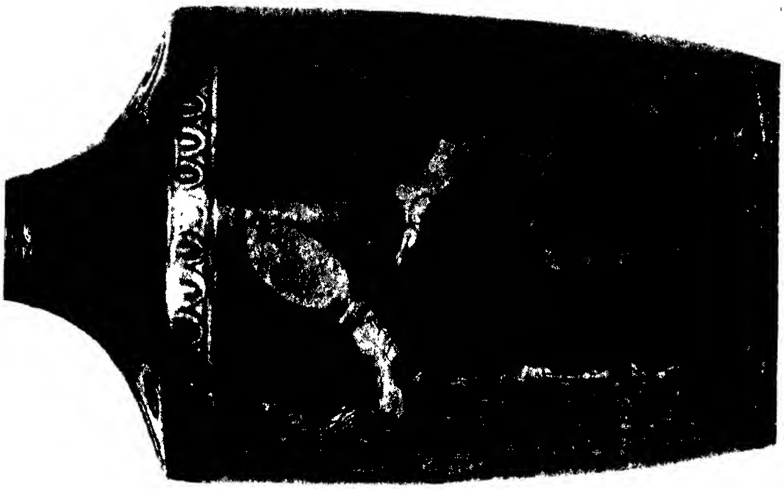

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this period (460-40 B.C.) the Nolan amphora (Aa 26),[1] the skyphos (Aa 29), the mug (Aa 31). The Nolan amphora has two scenes ; on the front a young man offering a young woman a quail, on the back a young man wrapped up in a cloak. The back is carelessly drawn and need not detain us. For the subject on the front the pyxis and hydria [2] in the Manchester Museum may be compared, but this is a finer work than either. The quail is a common offering from a lover to his lady. Our young man looks rather stupid but is certainly nervous, he tugs at his cloak ; the lady is also nervous, her head bends forwards, her hands are writhing. These expressive hands recall the Chicago painter's Eriphyle, who is bribed with a necklace to betray her husband.[3] But that is a heroic scene. Our painter is rather a follower of the Sotades painter who painted many excellent vases including the white ground cups in the British Museum ; [4] he has similar small compact figures with wide-open eyes. The skyphos (Aa 29) with a satyr holding a wineskin on each side belongs to the same period and broadly to the same school (Fig. 3-4).[5]

The mug (Aa 31) [6] shows us what our satyr looks like in the round (Fig. 5). It is interesting to compare these with satyrs of the archaic painters: the wild man of the woods is a type better suited to that decorated and cheerful period ; in the mid-fifth century the artist is more subdued and pensive and his interest is predominantly human. Perhaps we should find the same contrast, if we had satyr plays of Aeschylus and Euripides to compare. The plastic vase is as old a form as any in Greek pottery, it is the equivalent of the Caryatid in architecture. These head vases are the least successful kind. The later rhyton in the Manchester Museum is a much more pleasing work : the ram's head is the same shape as the bottom

[1] Herford, *op. cit.*, pl. 9*a* ; Beazley ascribes to the painter of London E 342 (*A.V.*, p. 325).

[2] *Manchester Memoirs*, lxxvii, pl. 2, 2 and 4. They are dated to 470 B.C. on p. 6 : 470-60 B.C. would be nearer the mark.

[3] Buschor, *Greek Vases*, fig. 142.

[4] Pfuhl, *op. cit.*, fig. 526-8.

[5] Compare particularly for the drawing of the breastbone a Kantharos by the Amymone painter, London E 155.

[6] Beazley, *J.H.S.*, 1929, p. 70.

of the drinking horn would be. The archaic plastic vases, particularly the Ionian, are better still; they are mostly small perfume vases in the form of ladies, warriors, animals, etc. Our vase is one of a group of five: three of them have pictures by one artist, the Carlsruhe painter. I think he also painted the warriors on the front of our mug, though they are carelessly drawn and there has been some retouching. The left warrior may be compared with a young man on a lekythos [1] in Oxford by the same painter; posture, cloak, treatment of eye and nose are very like; they are also very like on an alabastron [2] in New York.

There is a further step in realism for the painter to take—the representation of light and shade and the use of shading. In big painting this seems to have been achieved about 430 B.C. It involves of course emphasising colour at the expense of line. The vase painter who had only black, red, white, and gold on his palette could not follow here. He did try and liven up his vases by white figures, added gold, etc., but he could not go much further than this. But this development in big painting had a very important effect on drawing: since the volume of the figure and the contrast between it and its background is now represented by shading and colour, there is no need to suggest volume by the curves of the outline and the inner contours; therefore beauty of line is no longer an object: for the vase painter whose chief means of expression must always from the nature of his materials be line, this is a great loss. The lekythos in the School of Art (Aa 42) stands at the beginning of this development: it will have been painted about 420 B.C. There are still no figures in white or added gold, and there is still a beauty of line in the drawing of the chiton and himation of the seated woman. But the outline of both women is messy and jagged. It is interesting to compare it with certain white lekythoi painted soon after 450, where there is no attempt at modelling but the flat colour emphasises the expressive outline. The forerunner of the rich style is the Eretria painter: his technical skill is so great that his messy outlines can be forgiven. Our painter will be his contemporary and a little earlier than the

[1] *C.A.V.*, pl. xxxviii, I.

[2] Beazley, *A.J.A.*, 1932, p. 139.

fully developed rich style of the Meidias painter. This dating is confirmed by the ornament on the shoulder and under the handle.[1] The scene, a woman bringing a mirror to a seated woman, is very common at this time. At the beginning of the next century line becomes interesting again: there is an excellent example in the Kertsch hydria in the Manchester Museum.[2]

[1] Cf. Jacobsthal, *Ornamente*, pl. 125-9, p. 172; between the Schowalow painter and Aristophanes.

[2] *Manchester Memoirs*, lxvii, pl. 2, 3.

II.—The Expanding Universe as a Thermodynamic System.

By E. A. Milne, F.R.S.

(Being the Joule Memorial Lecture delivered before the Manchester Literary and Philosophical Society, February 27th, 1934.)

The lecture which I have the honour to deliver commemorates the work of James Prescott Joule, native of Salford, pupil of John Dalton, sometime secretary and president of the Manchester Literary and Philosophical Society. We honour him chiefly for his accurate evaluation of the mechanical equivalent of heat. Though he himself generously recognised that Count Rumford's work permitted a rough determination of the ratio of heat generated to work performed, it was Joule who in 1843 first stated explicitly the principle that there is a constant ratio, whatever the process, between heat generated and work performed, equal also to the ratio of heat lost to work gained in a process of converse type; and he estimated it as 838 foot-pounds per pound of water warmed through 1° F., a figure later revised by him to 772·55 under more carefully specified conditions.

Joule's scientific papers are a model of patient, objective, detailed investigation of proposed problems, and in these writings, devoted to the elaboration of precautions, the correction of observations and the development of laboratory procedure, he rarely allows us to see the inward excitements with which he must have been moved. But in his collected works, sandwiched between his earlier determinations of "J" in 1843 and his classical Royal Society paper of 1849, there occurs a report of a lecture delivered at the St. Ann's Church reading-room during his secretaryship of this Society,

and published originally in the Manchester " Courier " newspaper, May 5th and 12th, 1847, entitled " On Matter, Living Force and Heat."[1] In this lecture he breaks through his usual reserve and allows himself to speculate on the inner meaning of his discoveries and on their significance in the whole cosmos, with an intensity of conviction which is remarkable. Perhaps I may be allowed to quote some passages : " Matter is endowed with an exceedingly great variety of wonderful properties, some of which are common to all matter, whilst others are present variously . . . ; of the first of these classes, the attraction of gravitation is one of the most important." Again, " you see, therefore, that living force[2] may be converted into heat, and that heat may be converted into living force, or its equivalent attraction through space. All three, therefore—namely heat, living force and attraction through space (to which I might also add *light*, were it consistent with the scope of the present lecture)—are mutually convertible into one another. In these conversions nothing is ever lost." Again, on the real nature of heat, he says: "Heat must consist of either living force or attraction through space. In the former case we can conceive the constituent portions of heated bodies to be, either in whole or in part, in a state of motion. In the latter we may suppose the particles to be removed by the process of heating, so as to exert attraction through greater space. I am inclined to believe that both of these hypotheses will be found to hold good—that, in some instances, particularly in the case of *sensible* heat, or such as is indicated by the thermometer, heat will be found to consist in the living force of the particles of the bodies in which it is induced ; whilst in others, particularly in the case of *latent* heat, the phenomena are produced by the separation of particle from particle, so as to draw them to attract one another through a greater space." Lastly, " I do assure you that the principles which I have very imperfectly advocated this evening may be applied very extensively in elucidating many of the abstruse as well as

[1] Joule's *Scientific Papers*, 1884, p. 265.
[2] By " living force " he means of course *vis viva*, or kinetic energy.

the simple points of science, and that patient enquiry on these grounds can hardly fail to be amply rewarded."

That such enquiry has been amply rewarded is witnessed by the progress of thermodynamics and the kinetic theory of heat since Joule's work. The discovery of the first law of thermodynamics was followed by the isolation of the second law by Clausius and Kelvin, already (before Joule's time) adumbrated by Carnot. This has led to those grand but distressing conclusions about the whole universe which are now summarised in the phrase "the ultimate heat-death of the universe"—the conclusion that the universe must inevitably run down to a dull level of sameness in which energy is uniformly distributed and nothing interesting ever happens. We have seen how Joule was preoccupied with a connection between heat and gravitation. We should nowadays restate his ideas in terms of kinetic and potential energy, and of course we should not now assent to his cautiously expressed view that the phenomena of latent heat were due to gravitational attraction, for those were the days before the now-recognised identity of cohesive and electric forces. Nevertheless Joule's emphasis on the possibility of a connection between heat and gravitation affords one who was also for a short time one of your secretaries a pretext for discussing more fully the relation of the motion of all the particles of the universe to universal attraction and for enquiring whether the pessimistic "heat-death" conclusion can in the last resort be justified. I propose to consider briefly the phenomenon of the expansion of the universe by thermodynamic methods, that is, from the point of view of probability, and to allow myself to be led from this to attempt to say something on "the more abstruse as well as the simpler points of science."

Joule was concerned with pure thermodyanamics, macroscopic phenomena. It was Boltzmann who showed how entropy could be defined in terms of the *probability* of a given state of a dynamical system. Whereas Clausius and Kelvin emphasised the inevitability of the tendency of entropy to increase, Boltzmann and his successors showed that it was only highly probable that the entropy of a system would increase. Of all the detailed states of a dynamical system

compatible with the same macroscopic description, it was shown that the enormous majority of states will tend in a certain direction, will possess a tendency to even out differences of temperature and other inequalities, but that a small minority, a completely negligible minority in practice, would behave differently, would behave indeed in a very surprising way. This is usually expressed by saying that a kettle of water when put on a fire *might* freeze, or that a poker, put into the fire, *might* become red-hot at the wrong end. This is, of course, too dramatic a statement. The probability that the kettle of water might freeze is independent of whether we put it on the fire or not, and, besides, the state of being frozen would occur so momentarily that it would be unobservable.

There are two points to notice about the two different methods of establishing the "increasing property of entropy" respectively. In the method of Kelvin and Clausius, the appeal is to a generalisation based on experience: that if mechanical energy is gained at the expense of heat, then some other change must have occurred elsewhere in the universe, some other heat reservoir must also have gained heat. Or, alternatively, that when a process goes on of itself in the universe, that is when a natural process goes on, it can only be reversed and the participating bodies reduced to their initial state at the cost of causing some other alteration in the rest of the universe. To assign a numerical measure to the change of entropy in a natural process, and so verify that the entropy has increased, it is necessary to reverse the process by what are called technically "reversible steps," in such a way that the compensating effect in the rest of the universe consists of reversible transfers of small quantities of heat, whose associated entropy-changes are readily calculated. To carry out this process, there must be available some portion of the universe unaffected by the first process, a portion in which the new entropy-change can be definitely measured. If then the original process is a world-wide process—if every part of the universe happens to be affected by the process—there is no portion of the universe left untouched, so that we have no means of reckoning numerically the change of entropy—we have no standard—we

cannot test the alleged increase. If indeed the whole of the universe is affected by a process occurring in nature, then by the very circumstance that this is a natural or irreversible process we cannot undo it by reversible processes, so that we have no means of assigning a numerical measure to the change of entropy. Thus the proof of the increasing property of entropy, when based merely on that appeal to experience which we call the Second Law of Thermodynamics, breaks down at the beginning when applied to the whole universe. There is no means of measuring the change of entropy occurring in a process which affects the whole of the universe, so that no meaning can be attached to saying that the entropy has necessarily increased when we are limited to macroscopic methods. Careful scrutiny of the details of the proof due to Clausius and Kelvin, as ordinarily reproduced, confirms this. True as the inference necessarily is as asserted about any limited portion of the universe, it cannot with logical rigour be extended to the whole universe when the process itself affects the whole universe. We are deprived of our conclusion just in the most interesting case. Now the process of the emission of radiation by the stars and nebulæ would appear to be a process of just this kind ; it must affect minute changes of temperature in all the bodies of the universe. Again, the process of the expansion of the universe appears to be one to which every nebular system is subject : the distance of every nebula from every other is increasing. It is a one-way process. Is it accompanied with increase of entropy or not ? This leads us to the second type of proof of the so-called "increasing property of entropy," that based on microscopic analysis, due in principle to Boltzmann.

The usual analysis of the behaviour of a dynamical system in relation to its thermodynamic properties depends on the system being an *enclosed* system. The system must be enclosed by some physical boundary, which exerts a confining field of force on the particles of the system. Let us examine whether the increasing property of entropy still holds good when we remove the physical bounding-walls from such a system—let us examine whether the system continues to pass, inevitably, from a less probable to a more probable state.

We shall show, by considering first a particular case, that the theorem is no longer necessarily true; we shall find that a system of moving particles without boundary, endowed initially with a random distribution of velocities, tends to lose the property of randomness and to become possessed of a systematic correlation of position with velocity.

Before going into detail I will briefly outline the process of idealisation used in my analysis of the universe, to which the following is an introduction.

The universe as it is is too complicated a thing to handle. According to the problem on hand we have to make an abstraction of the elements essential to the problem. The universe is believed to consist of stars, star-clusters, gaseous nebulæ and obscuring clouds (to name only some of its contents), mostly concentrated in galaxies, often called "spiral nebulæ." When I speak of the universe as a thermodynamic system, I have in mind the distribution of these galaxies or spiral nebulæ in space, their motions and their life-history. For some purposes we may idealise the galaxies by representing each by a particle; this is convenient when we want to discuss their motions and distributions. For other purposes each galactic system may be represented as a collection of particles possessing a variety of motions. Again we can regard the existing galaxies as the vestiges of the primeval distribution of matter and motion in the universe, a distribution describing the behaviour of the ultimate particles which have later become in part agglomerated into stars and in part have remained free. In any case an essential step in the process of idealisation is the reduction of the universe to a crowd of particles.

The interactions between the members of such a crowd are of two kinds: the general forces of gravitation acting between them and the forces arising in collisions. Both kinds of forces may be described by means of a dynamics—a system of relations involving the notions of force, mass, energy, and momentum. But dynamics is a system originating out of observations of the kinematic behaviour of matter. We cannot assign mass to a particle by thinking about it, or by direct perception or judgment. Mass is

assigned by comparison of accelerations. And accelerations are kinematic things—observable in principle by a stop-watch and a metre scale, or in the last resort, as can be shown, by a stop-watch only. Even if we use a spring balance, kinematics comes in in the displacement of the pointer. Similarly mechanical energy, as in Joule's fundamental experiments, has to be calculated from kinematic observations. It is far more basic, then, when discussing the universe to skip that intermediate construct *dynamics* and deal with the primary kinematic behaviour of the system to which the universe has been idealised. Dynamics is simply a construct from kinematics: for example, Newton's dynamics and gravitation were a construct from Kepler's kinematics. Dynamics is an intermediary between man and motion, and essentially is unnecessary.

Dynamics dispensed with, we dispense with the concept of force and are left simply with accelerations. If our problem is the behaviour of a system of particles, we require a principle which either describes or predicts their accelerations directly, that is, summarises the totality of accelerations undergone by the members of the system at all times. The train of thought which I have been developing during the last eighteen months does in fact lead to a terse description of all the accelerations occurring in the world in certain idealisations of the world.

Now when we have arrived at a naturally occurring system of accelerations, then we have arrived at gravitation; we employ Einstein's principle of equivalence in a new form, and identify a naturally arising field of accelerations as a field of gravitation. This can be accomplished without introducing any dynamical concepts whatever, and moreover without inferring a dynamics as a consequence of an assumed geometry. To reduce gravitation and dynamics to the geometrical properties of space, to endow space with structure in order to describe the phenomena occurring in it, is one way of abolishing action at a distance; but it is equivalent to reintroducing an æther. This is a perfectly legitimate proceeding, if we shut our eyes to its ultimate consequence of restoring something absolute to the world—a highly

unattractive climax. But the interesting thing about the investigations I am about to describe is that they eventually lead to a description or prediction of phenomena without using either action at a distance or an æther. However interesting it may be that we can describe the totality of motions in the world by means of a curved space or an æther, it is still more interesting that we can describe them without using an æther at all, without even using space as a concept, using in fact only the totality of permissible (i.e. practicable) observations for mentioning what occurs, and embodying them in a general kinematical principle which we have reason to expect these observations will satisfy. If the principle is finally dubbed "teleological," all I can say is, so much the better for a teleological view of things. The systems of Newton and Einstein begin with *parts* of the universe, limited systems, and enunciate principles governing or describing the behaviour of parts. What I have been trying to do is to consider the universe, at one blow, as a whole. The cosmology of Einstein and his successors has been in effect also driven to do so. For it has been found necessary in certain developments of their theories to introduce a certain "cosmical constant," equivalent to introducing certain components of acceleration as occurring proportional to the distance of the particle experiencing it from the particle "causing" it. Thus every particle, in this view, becomes more important the further it is away, and it is impossible *ab initio* to consider the phenomena in a limited region as influenced only by the matter present in that region. The whole universe must be taken into consideration from the start. From one point of view this climax in the employment of action at a distance is a *reductio ad absurdum*; it *is* absurd to make each particle more important the more distant it is. It is true that the effect of this distance-proportional acceleration can be described by means of differential equations holding locally. But a differential equation is of no use without boundary conditions, and the boundary conditions necessarily involve the distribution of matter at great distances. Instead of beginning with differential equations and boundary conditions, or with improbable actions at a distance, I have found it pos-

sible to proceed, purely kinematically, from a principle which in its various particular forms amounts simply to denying that there exists any preferential frame of reference in the universe at all, or to asserting that the totality of occurring motions must be such as to frustrate for ever any attempt to average them so as to lead to a unique position for the mean-centre of the universe or a unique vector for its mean velocity. Essentially it is the extension to all accelerated motions of the principles embodied in that particular case we call Einstein's special theory of relativity. I have not here the time to describe in detail these investigations, much of which is unpublished. What I propose to do is to describe the earlier simple views out of which they originated.

Amongst all the possible systems of accelerations of a system of particles, the simplest is that in which all the accelerations are zero. We need to analyse this fully in order to have a background or standard of comparison against which we can view more complicated systems of accelerations. But it has a greater importance than this, for the line of thought I have pursued leads to the prediction that when we idealise the universe to a system of particles (with velocity correlated with position) in which one particle represents each nebula or galactic system, then this system of particles could actually have, in nature, zero acceleration everywhere. This is not to ignore gravitation, or leave it out. In dynamical terminology it simply means that the resultant gravitational force, due to the totality of material present, reduces *at each particle present* to resultant zero. I do not assert that every nebula in the actual universe is actually in a vanishing gravitational field. The rotations, the outward motions and the spiral forms, of nebulæ are evidence to the contrary. They are most probably "due" to the residual gravitational fields arising from the imperfect way in which the actual nebulæ realise the ideal scheme, to put the matter dynamically. Kinematically speaking, the nebulæ are not arranged with the mathematical niceness of the simplest ideal scheme, and their failure to be so arranged must lead to still further details of motion in order to continue to conceal the emergence of any preferential frame of reference that would otherwise be disclosed by de

partures from the ideal scheme. I believe this to be a powerful idea—that the manifold complexities of order and motion in the actual universe as observed are but the teleological consequences of the impossibility of arranging a three-dimensional system of *discrete* particles in exact accordance with the simple continuous laws predicted by the methods of statistical kinematics. A dust-cloud could be arranged, in a finite space, with non-zero density, so as to yield zero gravitational acceleration for each particle. Let the dust-particles be agglomerated into discrete condensations or centres, and it becomes impossible to avoid a "corner-y-ness," an emergence of slightly distinguishable views of the whole system from "corner"

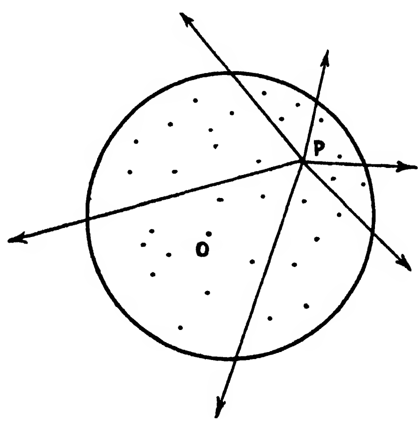

FIG. 1.

to "corner," which in turn is accompanied by what ordinarily we call local accelerations, tidal couples, and the like, but which are here to be regarded as further adjustments to prevent the arising of a nameable frame of absolute rest for the universe when its average properties are evaluated.

Let us examine then the behaviour of a system of particles possessing zero accelerations and undergoing no collisions. Let us choose a moment at which the system is first *given*, and call it $t = t_0$. At $t = t_0$ we know all the positions of all the particles, and all their velocities. These can be chosen in an infinite variety of ways. For simplicity we will examine a finite number of particles occupying at $t = t_0$ a finite volume

without physical boundary. What is the later behaviour of the swarm?

Since the accelerations are zero, each velocity is constant. Take some interior particle O as reference particle and consider the neighbourhood of a point P inside the volume occupied by the swarm. Here there may be particles moving in all directions, some outwards, away from O, some inwards. But every particle, given a long enough time after $t = t_0$, will ultimately be moving outwards as viewed by O. An outward moving particle just moves outwards into the originally unoccupied space and continues outwards. An inward moving particle first approaches nearer O, following a straight line, attains a minimum distance from O, then begins to recede, eventually moving almost directly away from O. Ultimate

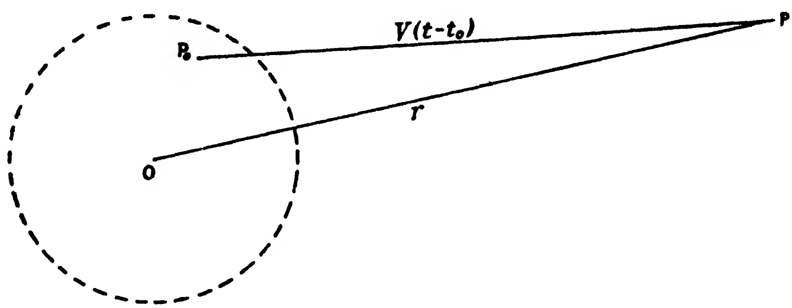

FIG. 2.

recession prevails. However randomly distributed the initial swarm with respect to the directions of the given velocities, after a sufficient time the motions are systematically motions of recession from O. Out of chaos we get system. This is the first departure from the teachings of traditional thermodynamics; the systematic recession is generated whatever the initial velocity-distribution. In the course of generating systematic recession, the swarm expands, into the previously unoccupied space.

Now consider the spatial distribution of the particles. By time t, a particle of velocity V has covered a distance $V(t-t_0)$. After a sufficient interval, this will be large compared with the initial distance of P_0 from O, and we can say that approximately $V(t - t_0)$ is the distance r of P from O.

Thus $$r \sim V(t - t_0)$$

or $$V \sim \frac{r}{t - t_0}. \quad . \quad . \quad . \quad . \quad (1)$$

We now notice that the fastest particles will have gone the greatest distances, and be furthest from O. The fastest particles will accordingly ultimately form the frontier of the expanding swarm. They will be followed by the next fastest, and so on. At any time t sufficiently large, the original volume will be occupied only by the very slow-moving particles. If the original swarm includes representatives of all velocities, the original volume will always be occupied by *some* particles, including those initially at rest or almost at rest. Inside this original volume there will always be a mixture of directions of approach and directions of recession, but the velocities ultimately surviving will always be very slow ones. Outside the original volume a process of velocity-segregation will go on, by which velocity and position become increasingly correlated. The degree of correlation is easily seen from the following diagram :—

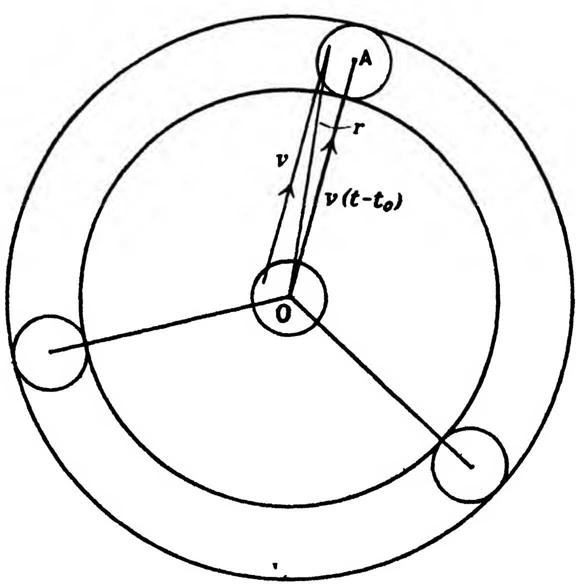

FIG. 3.

For the sake of illustration let the original volume be a sphere of radius a, centre O. Consider all the particles with speed v, whatever the direction. Describe two spheres of radii $v(t - t_0) + a$, $v(t - t_0) - a$. Then all these particles, at time t, will lie between these two spheres. Those moving with velocity v parallel to OA will all occupy the new sphere obtained by displacing the original sphere of radius a through a vector distance $V(t - t_0)$, parallel and equal to OA (Fig. 3). Hence r lies between $v(t - t_0) - a$ and $v(t - t_0) + a$. Hence

$$v - \frac{a}{t - t_0} < \frac{r}{t - t_0} < v + \frac{a}{t - t_0}$$

or

$$\frac{r}{t - t_0} - \frac{a}{t - t_0} < v < \frac{r}{t - t_0} + \frac{a}{t - t_0}.$$

This shows at once that the larger is t, the more accurately is v given by (1). There is always, in any given distant region, a mixture of particles with slightly differing velocities, but the segregation becomes purer and more perfect as time advances.

Ultimately we have a " disciplined " and expanding swarm, in which any particle P possesses the property that particles inside P are moving more slowly and particles outside P more swiftly. The system has now one of the characteristics of a hydrodynamical motion of flow—at each point there is a unique, or almost unique, velocity.

Out of chaos we have arrived at order: systematic recession, systematic expansion, correlation of velocity with position. All these stand in marked contrast with the behaviour of the systems considered in statistical mechanics. We violate the conclusions of statistical mechanics because there is present, in effect, a Maxwell's sorting demon. Everyone remembers how Maxwell invented an imaginary sprite who stood near a small aperture in a partition separating two specimens of gas, and opened the aperture whenever a fast-moving molecule approached, closed it whenever a slow one approached. He thus concentrated the faster moving molecules on one side of the partition, the slower moving ones on the other, and so generated a difference of temperature

between the two sides. The notion of temperature is foreign to our system of particles, but we see that the " empty space " surrounding a cluster of particles acts as a Maxwell's sorting demon to the cluster, for it segregates the fast ones near the expanding frontier, causing a velocity gradient as we pass back to the central, almost stagnant region. This shows that the results of thermodynamics must be used with much caution when we want to apply them to a non-walled-in system.

Let us examine our system further. Can we say that it is necessarily always an expanding system ? Clearly some consideration is necessary, for it is quite easy to construct a contracting system. All we have to do is to reverse the velocities of all the particles in a system observed to be expanding, in order to construct a contracting system. It would almost appear from this simple example that contracting systems are as frequent as expanding systems. We shall see that this deduction would be false and rests on an obscurity of thought.

Take any system at time $t = t_0$ and let it follow its natural motion. Then it ultimately expands and goes on occupying larger and larger volumes. Now reverse all the velocities ; it now retraces its configurations in reverse order. The volume is now diminishing. But the now-reversed system must ultimately become an expanding one, by the same argument as before. Hence it must have at least one configuration of minimum volume, and it is easy to see that there can only be one such (for an expanding system cannot of itself begin to contract). It will have assumed this minimum-volume configuration at some epoch in the history of the direct (forward) motion of the system. When was this epoch ? The interesting fact is that in the overwhelming majority of cases, the epoch of minimum volume is the epoch $t = t_0$ at which the system was first " given."

For consider the system as given. If it possesses, distributed near its original frontier, a set of outward moving particles it must be, at $t = t_0$, an expanding system. But if it possesses also inward-moving particles, its velocity-reverse will also expand at this moment. Hence in these cases, since both the system itself and its velocity-reverse are expanding

systems at $t = t_0$, $t = t_0$ must be the epoch of minimum volume. But very special conditions must be satisfied in order to avoid this state of affairs. To avoid it, either the system at $t = t_0$ must be an expanding system and its velocity-reverse a contracting system, or the system itself must be a contracting system and its velocity-reverse an expanding system; or both must be non-expanding systems. But for a distribution taken at random, there will always, in any neighbourhood of the frontier, be both outward-moving and inward-moving particles. Thus for the overwhelming majority of *given* systems, the initial volume is the minimum volume.

The epoch of minimum volume of any system may be called the natural zero of time for this system, $t = 0$. After the zero of time, the system is an expanding system. Before the zero of time, it was a contracting system. Thus for the overwhelming majority of given systems, the natural zero of time $t = 0$ is the epoch $t = t_0$ at which the system is first given, and so $t_0 = 0$. Hence for the overwhelming majority of systems, if a system is viewed at any epoch after the epoch at which it was first given, it will be found to be an expanding system, with systematic recession, outward motion of particles and velocity segregation according to (1).

The natural zero of time divides the history of a system into two periods, in the first of which it was a contracting system, in the second an expanding one. Thus in one sense every system has a past history in which it was a contracting system. But *observation* will seldom allow the view of a contracting system. For a system can only come into existence by being first given, and then any epoch of observation is necessarily later than the epoch at which it was first given; hence, viewed at this epoch the system will be found, in general, to be expanding.

We may put the matter otherwise. Suppose that a large number of systems are thought of as started off, or given, at the same epoch t_0. Then let the systems be all viewed at some later time. All save a negligible minority will be observed to be expanding systems. There will be a small proportion such that immediately subsequent to t_0 they began

to contract, owing to special arrangements of the velocities of their particles such that they have still not reached their minimum volume. These will be observed to be contracting systems. These, too, will in the course of time reach their minimum volume and then expand. The rest, the overwhelming majority, will expand from the moment t_0 at which they were first given.

Contracting systems are, as we have seen, easily constructed. To every expanding system corresponds another system, its velocity-reverse, and except at the natural zero of time this is a contracting system. To construct a contracting system, then, we have merely to take a system at random, let it expand a little so as to get away from the configuration at its natural zero of time, and then reverse the velocities. An expanding system not at its natural time-zero is just as special a system as a contracting system; specialisation, velocity segregation, has already set in. It is therefore an exceptional system, not comparable with the majority of systems selected at random. It is not the characteristic of *expansion* which differentiates a special system from a random system; it is the characteristic *of being on one side or other of its natural time-zero.* In order to be observed or looked at, a system must first have been given, and the moment of observation is therefore necessarily later than the moment of being first given, and so, not necessarily but in the enormous majority of cases, later than the natural time-zero. The moment of observation will therefore almost always reveal the system as an expanding one.

We have here a result exactly parallel to the statistical formulation of the second law of thermodynamics. In that formulation it is not certain that a system will increase in entropy, but only highly probable; the overwhelming majority of systems behave so as to increase in entropy; but a system of decreasing entropy is readily constructed by reversing all the velocities. Hence a system taken at random almost certainly increases its entropy. In our investigation a system taken at random almost certainly expands. There is, however, a difference. In the case of the Second Law we cannot assert that away back in its past history

it was a system of decreasing entropy. In our result it is possible to assert that every expanding system was once a contracting one, but the proposition is, in general, incapable of confirmation or disproof by observation. Only propositions relating to epochs later than the epoch at which the system was first given are propositions capable of being tested by experience.

There is nothing actually paradoxical about this. Only verifiable propositions have a real content; this is what once Locke, later again Einstein, taught us. If a proposition is not verifiable it is meaningless. Thus propositions about the state of a system prior to the moment at which it was first given are meaningless. Hence for any proposition about a system to have a meaning, the system must have been first given. The proposition that any system when observed must be an expanding system has a meaning and is statistically true; the proposition that such a system was once a contracting system is in general meaningless; for, for the overwhelming majority of such systems, the epochs at which the system was contracting were anterior to the moment at which it was first given. It is highly interesting that such a simple situation as a swarm of particles, kinematically considered, involves an appeal to the theory of knowledge.

The application of these ideas to the whole cosmos is obvious. To the extent to which the universe can be idealised to a set of acceleration-free particles, it is enormously probable that, when observed, it will be found to be an expanding system. This seems to me the essence of what is sometimes considered the mystery of the expanding universe.

Is there any confirmatory evidence of this explanation? Fortunately there is. The observed nebulæ are found to be not only receding from us (with exceptions only near ourselves which are permitted by our explanation), but to be receding according to a velocity-distance proportionality. The further a nebula is, the faster it appears to be moving, as judged by the Doppler effect in its spectrum; and its velocity is proportional to its distance. This is just what our explanation predicts. The formula $v \sim r/t$, where t is measured from the natural time-zero, means that at any

one epoch t, the velocities of the nebulæ are proportional to their distances from any one of them. Actually the data giving observed Doppler effects refer not to a common epoch t throughout the universe, but to a common epoch of observation T. If allowance is made for the time of travel of the light, the velocity of a nebula observed at epoch of observation T to be at distance r is given by

$$v = \frac{r}{T - r/c}.$$

Observations of distances are not yet sufficiently accurate, nor are they yet made at sufficiently large distances, to distinguish between this more refined formula and the simple one $v = r/T$. As it is, the observed velocity-distance proportionality, discovered by Hubble, is just what we should expect for a set of unaccelerated nebulæ once started. Moreover the observations give an estimate of the distance in time of our present epoch from the natural zero of time, for our universe. Hubble's law states that the velocity mounts up at the rate of about 500 kms. per sec. per 10^6 parsecs, where 1 parsec is $3{\cdot}08 \times 10^{13}$ kilometers. Hence t in seconds is about

$$\frac{10^6 \times 3{\cdot}08 \times 10^{13}}{500} = 6 \times 10^{16},$$

or (since 1 year $= 3{\cdot}16 \times 10^7$ seconds) about 2×10^9 years. This is the time ago of the natural zero of time, for our universe.

We can now discuss the question: Was the universe ever a contracting system? We have seen that we can retrace the history of any expanding system until it appears as a contracting system. But a proposition to the effect that the universe *was* once a contracting system would only be possessed of a meaning if it could be verified by observation. We have seen that if the universe was ever first given, then it was enormously probable that the instant of being given was the natural zero of time, and hence if ever it is viewed, necessarily at an epoch later than when it was first given, the view will take place after the natural zero of time and so expose it as an expanding system, as observed. It is possible, though enormously improbable, that the universe, if ever

first given, was given at a moment in its history antecedent to its natural zero of time; in that case observation of the universe at any epoch in between the moment when it was first given and the natural zero of time would show it a contracting system. Hence the answer to the question whether the universe, at any epoch at which it was observable, was a contracting system depends simply and solely on the answer to the question: Does the universe contain evidence of events which occurred before the natural zero of time? In other words, is there any evidence that events occurred more than 2000 million years ago? It is highly improbable, *a priori*, that there will be any such evidence.

It is well known that the most satisfactory evidence of events at this order of time ago is provided by the radioactive minerals in the earth's crust. The oldest known minerals from their uranium/lead ratio indicate an age between 10^9 years and 2×10^9 years, whilst the amounts of uranium and lead in the earth's crust indicate an age less than 8×10^9 years.[1]

The approximate coincidence of these periods of time with the value of t deduced from the recession of the nebulæ has been frequently pointed out. Our point is here that they do not exceed the value 2×10^9 years, and that this is in accordance with our argument which showed *a priori* the unlikelihood of the universe being *given* in time more than 2×10^9 years ago. Other geological estimates, which of course refer to *events*, like the formation of the ocean, yield smaller ages. Other, astronomical, methods of estimating the age of the universe are well known to be discordant and to yield an age some thousand-fold greater, but they are all essentially extrapolations and the event they date back to is a *hypothetical* event, such as the formation of a double star by fission; also they assume that the "constant" of gravitation G has always had its present value, whilst my own researches indicate that the effective G is only apparently constant in time, obeying a proportionality $G \propto t$ and so now increasing by approximately one part in 2×10^9 per year.

[1] Jeffreys, *The Earth*, 1924.

This is not the occasion to discuss the details of these other astronomical methods. The most certain evidence, the radio-active, is in accordance with the nebular recession estimate. As pointed out by many, it places the epoch of the formation of the earth in the vicinity of the moment of closest approach of all the matter forming the universe, when on dynamical grounds the formation of a solar system has its highest probability. (We notice in passing that the same argument points to the probability of the existence of solar systems in other nebulæ, for there is no difference in probability from nebula to nebula.) We may therefore be content to conclude that there is no trustworthy evidence of the occurrence of observable events more than 2×10^9 years ago. Hence no observable events occurred before the natural zero of time for the universe. Any other conclusion is in any case highly improbable—of the same order of probability that the kettle will freeze when placed on the fire—so that the conclusion may be taken as to all intents and purposes *certain.*

It follows that there was an epoch at which the universe was first *given*, and that this epoch is 2×10^9 years ago by our ordinary standards of time as kept by ourselves. The contrary conclusion (equivalent to the assertion that the universe *was* once a contracting system) would not only relegate the moment of being given to a more distant epoch, it would require an enormously improbable configuration for the "initial" configuration, whether this occurrence took place at a finite negative epoch $t_0 < 0$ or at $t_0 = -\infty$. As there is only one universe, the word "probable" cannot have here its more usual counterpart in terms of frequency, but there is a general sense in which we may say that such an initial configuration would have to satisfy highly special conditions. The universe satisfies highly special conditions *at present*, but it has passed naturally to this state, in the way we have seen; that is a different matter from being arranged to satisfy special conditions. Speaking quite reverently we may say that it would be enormously more difficult, would require enormously more attention to detail, for God to construct a universe in a configuration other than that of its natural zero of time. If there were evidence that the universe had

existed, had been the seat of events, before the actual zero of time, it would be the most splendid argument from design that could possibly be imagined.

To conclude that there was an epoch when the universe was first given cannot be distinguished from concluding that the universe was once created and that it was created not as an exceptional system but as a perfectly ordinary system, as probabilities go. There is no room for an argument from design. Here I use " created " in a purely subjective sense, namely that there are *for us* no events we could have observed earlier than this epoch. What is the state of affairs for other observers?

By another observer we must mean an observer on some other nebula. Such a nebula is moving relatively to us, say with speed of recession V given by $V = r/t$. The important thing about this formula is that it is relativistically invariant—the same law of expansion will be observed by any other observer of the system of nebulæ, moving with one of the nebulæ. (Hypothetical observers not attached to some nebula must of course be excluded.) Suppose that an observer B on some definite nebula, moving with uniform speed V, also reckons time from the natural zero of time. He was then in our vicinity, and his observations x', y', z' of an event which occurred (in his experience) at time t' are connected with ours $(xyzt)$ by the usual Lorentz formulæ,

$$x' = \frac{x - Vt}{(1 - V^2/c^2)^{\frac{1}{2}}}, \quad y' = y, \quad z' = z, \quad t' = \frac{t - Vx/c^2}{(1 - V^2/c^2)^{\frac{1}{2}}}.$$

Suppose that this event occurs on a nebula moving with velocity components u, v, w; then as it is a member of the system,

$$u = \frac{x}{t}, \quad v = \frac{y}{t}, \quad w = \frac{z}{t}.$$

The second observer observes its velocity-components u', v', w' as

$$u' = \frac{dx'}{dt'}, \quad v' = \frac{dy'}{dt'}, \quad w' = \frac{dz'}{dt'}.$$

Hence

$$u' = \frac{dx - \mathrm{V}dt}{dt - (\mathrm{V}/c^2)dx} = \frac{u - \mathrm{V}}{1 - u\mathrm{V}/c^2} = \frac{\dfrac{x}{t} - \mathrm{V}}{1 - \dfrac{x}{t} \cdot \dfrac{\mathrm{V}}{c^2}} = \frac{x'}{t'},$$

$$v' = \frac{dy(1 - \mathrm{V}^2/c^2)^{\frac{1}{2}}}{dt - (\mathrm{V}/c^2)dx} = \frac{v(1 - \mathrm{V}^2/c^2)^{\frac{1}{2}}}{1 - u\mathrm{V}/c^2} = \frac{(y/t)(1 - \mathrm{V}^2/c^2)^{\frac{1}{2}}}{1 - \dfrac{x}{t} \cdot \dfrac{\mathrm{V}}{c^2}} = \frac{y'}{t'},$$

and similarly

$$w' = \frac{z'}{t'}.$$

Thus the same law of expansion is observed by the second observer, B.

Now let him observe events *at himself* so that $x = \mathrm{V}t$. Then

$$t' = \frac{t - \mathrm{V}t \cdot \dfrac{\mathrm{V}}{c^2}}{(1 - \mathrm{V}^2/c^2)^{\frac{1}{2}}} = t(1 - \mathrm{V}^2/c^2)^{\frac{1}{2}}.$$

Hence an event observed by us as occurring near B at time t (reckoned from the natural zero) is observed by him as occurring at the "earlier" time $t(1 - \mathrm{V}^2/c^2)^{\frac{1}{2}}$. This is a well-known result in the abstract theory of relativity, popularised by illustrations involving high-speed aviators. What has been somewhat lost sight of is that the distant nebulæ are precisely high-speed aviators, and that they afford probably the only concrete example of an application of the result to actual phenomena. t is simply the age of the universe, reckoned by our ordinary clocks, at the moment of occurrence of the event we observed at B. (We observe it, of course, later than t, owing to the finite time of travel of light, but we can calculate back; t is the time finally assigned by us.) Thus observer B reckons the universe as younger than we do, at the same event. He sees the nebulæ as closer together than we do—the universe is less expanded. What he calls his "present" is to us the analogue of some epoch back in our past history, when to us also the universe

was less expanded. He is nearer the zero of time in his own reckoning than we are in ours.

We see that the phrase the "age of the universe at a given event" has no objective content. It depends on the observer who observes that event. A whole range of times can be assigned to the same event, depending on the observer who observed it. We assign the age t. The observer near it assigns the smaller age $t' = t(1 - V^2/c^2)^{\frac{1}{2}}$. Other observers may assign different ages. Alternatively, we ourselves as observers can survey the world in our "present," and we then find that all these events, instantaneous for us, are assigned smaller ages by the observers who, in the vicinities of these events, are experiencing them. We are thus the oldest inhabitants of the universe, in our own reckoning; all other observers reckon the world as younger than we do, at the world-wide class of events which are simultaneous to us.

As soon as we pay attention to the relativity of the universe, we must make use of what is conveniently called "the cosmological principle," the principle that all nebulæ in the universe must be on the average equivalent to one another. To deny this principle would be to assert that there are preferential points of view in the universe, that the universe does not appear the same from whatever point it is observed. That might indeed be the case; but if so observation will only disclose it if we first construct a universe which would appear the same from all points of view and then compare the description of the constructed universe, as it would be seen by ourselves, with what we actually observe. The construction of an idealised universe which appears the same everywhere is a necessary step in the analysis of our experiences. It is called "a solution of the cosmological problem." Such a solution was constructed by Einstein by the use of a finite closed space of uniform curvature, and this "space" was further supposed by his successors in the subject, to be itself "expanding." "Expanding space" as a physical entity is meaningless, we cannot attach a meaning to expanding "emptiness"; it is, in fact, only a convenient name for describing a field of force variable with the time, or a set of metrical relations variable with the time. The only way

of comparing its consequences with experience is to describe the behaviour of particles in the space, and once we have reduced the implications to assertions about the motion of particles we may as well dispense with the non-static space and return to ordinary static Euclidean space, which is itself only a useful scaffolding constructed out of observations of events, conventionally reduced to assignments of distance and epochs. I have shown elsewhere that it is possible to construct a continuous system of moving particles in ordinary three-dimensional space such that its description from any member of the system is the same as from any other member.

The simplest way of arriving at it is to construct first a system of *velocities* whose statistics are the same as reckoned from any one of the particles moving with one of the velocities. Mathematical analysis using Euclidean space and the special theory of relativity, shows that this system of velocities is necessarily of the form

$$\frac{\mathrm{B}\,du\,dv\,dw}{c^3\left(1 - \dfrac{u^2 + v^2 + w^2}{c^2}\right)^2},$$

(u, v, w) being the components of velocity. Many critics of my work have expressed surprise at such a distinctively non-Maxwellian velocity-distribution. But a Maxwellian distribution is the expression of the results of repeated interactions amongst a set of particles; it is something which is brought into existence in the course of time. The above law is, on the other hand, the expression of the distribution of velocities possessed by a system of particles moving each with a constant velocity and possessing no preferential frame of rest. It is simply the expression of the non-existence of a velocity-centroid. If the system of particles had a mean motion, that would be an absolute thing. There would be one frame of reference pre-eminently distinguished from all others, namely the frame in which the system as a whole is "at rest." The question would then arise, how is the system to recognise this frame? If we permit ourselves an anthropological mode of expression, how is the system to "know" how to fix this frame in the waste of featurelessness which

" space " is. If it could fix it, there would have to be some distinctive, recognisable feature of this frame, contradicting the structurelessness of space. If the universe actually determined a frame of rest in space, we should want to ask (but be unable to answer the question), what made the universe light on this particular motion when it was created; why does it assume such and such as a standard of rest instead of such and such other apparently equally good frame? It is scientifically and æsthetically far more satisfying to recognise the featurelessness of space at the outset; the system of velocities, coming into existence at $t = 0$, must then be such that to it all frames of reference that can legitimately be adopted, however moving, are equally suitable. A simple case of such a distribution of velocities is that given above. If a single velocity in the distribution were altered from this standard distribution, a preferential direction would immediately be selected. Only those alterations in velocity are permissible or possible which continue to make impossible the selection of a preferential frame.

It is quite possible to enumerate distributions of particles in non-uniform motion which satisfy the same condition—that they disclose no preferential standard of motion. I have elsewhere enumerated a whole class of such distributions. We may describe the occurring accelerations as resulting from interactions between the particles, if we choose. I have in fact reduced the accelerations to actions at a distance of the type of Newtonian attraction and cosmical repulsion, which in the simplest (hydrodynamical) case may be described as just balancing. But all talk of forces or action at a distance is a mere human device. I do not believe that the statement that free particles move towards one another because they attract one another has any meaning whatever. Or we may reduce the motions to the " effects " of a " curvature of space "—another human invention. I do not believe that curvature of space—the structure of structurelessness—has any objective meaning whatever in nature. Gravitation is just the description of the totality of motions which the totality of particles in the universe are undergoing in order to yield no possibility of analysing their motions so

as to give recognisable differences between different frames of reference differing in their directions of motion or relative speeds. In even the simplest gravitational phenomenon every particle in the universe takes part—whether it be the relative shift of spheres in Cavendish's experiment, the motion of a projectile or the motion of a planet. (It must be remembered that even in a so-called statical experiment "force" is indicated by motion—by the displacement of the indicator of a spring-balance, for example; no determination of force is at bottom purely statical.) I have already admitted that this gives to the universe a teleological aspect, an almost purposive direction, a dependence of all its constituents on one another in executing a common aim. But why not? Abstract problems in gravitation, like the problem of two bodies, are essentially illegitimate abstractions in the real world; any real problem in gravitation involves the whole universe, especially in those handlings of it which introduce as an action at a distance "cosmical repulsion." Instead of building up solutions of the cosmological problem by making complex syntheses of isolated abstract situations, it is enormously more convenient to discuss at one blow the totality of particles and motions present. It ought indeed to be possible to discuss any gravitational situation by a similar method. Thus in a universe consisting of a small test particle in motion round a massive one, there is actually a centre, namely the massive particle (this defines "massive") and the motion must be one of the class such that a certain distance, namely distance from this particle, has a meaning and is capable of determination by observation. In such a special problem the special theory of relativity would, of course, be inapplicable, for the special theory of relativity is simply the expression of the equivalence of observers in uniform relative motion with as its consequences, the non-existence of absolute distance and absolute velocity. Thus, whilst the special theory of relativity will be inapplicable to any special gravitational problem, in which by its very specification absolute measures are involved, it is essentially applicable to the whole universe, to which essentially no absolute frame can be ascribed—unless we can find some observable

feature in the space which would then be called absolute. Even then, some other frame would be required in which to fix this new absolute, and unless we introduced an infinite regression of frames of reference we should be led in the end, again, to the special theory of relativity.

The above system of uniform motions

$$\frac{Bdudvdw}{c^2\left(1-\frac{u^2+v^2+w^2}{c^2}\right)^2},$$

by the principles described at the beginning of this lecture, tends to generate the spatial distribution of velocities for which

$$u=\frac{x}{t},\quad v=\frac{y}{t},\quad w=\frac{z}{t}.$$

Performing the substitution, the spatial distribution of density tends to assume the form

$$\frac{B\frac{dx}{t}\cdot\frac{dy}{t}\cdot\frac{dz}{t}}{c^3\left(1-\frac{x^2+y^2+z^2}{c^2t^2}\right)^2},$$

or

$$\frac{Btdxdydz}{c^3\left(t^2-\frac{x^2+y^2+z^2}{c^2}\right)^2}, \qquad . \quad . \quad (2)$$

This may therefore be considered as the simplest possible idealisation of the world. It yields a universe contained in the interior of the expanding sphere

$$x^2+y^2+z^2=c^2t^2,$$

and a particle-population more and more crowded towards the inner boundary of this sphere. The total population is infinite in number. By its mode of construction, every particle has the same relation to the whole as every other particle, and it is readily verified that every particle sees itself in fact as the centre of the expanding sphere. In this idealisation, if we trace the motion backwards to $t=0$, the spherical cluster shrinks to a point: the initial configuration, the configuration at the natural zero of time, has become

idealised to a point. We need not press this aspect of the idealisation too far. The concept of an initial configuration, of a system at the moment of being first given, of a "creation," is at present so unfamiliar that it would be out of place here to attempt any further discussion of the singularity which appears to represent such initial configuration. I will only say that my later investigations (not here given) of a more detailed solution of the cosmological problem on these lines yields a great many of the observed features of the system of the nebulæ.

The simple hydrodynamical system (2) has many wonderful and surprising properties. Here I only propose to direct attention to the circumstance that it includes representative particles moving at all speeds up to that of light. It includes particles—or nebulæ—moving within any assignable range, however small, of the velocity of light. That means that the universe, in order to satisfy the condition of containing no unique centre or unique velocity frame must contain nebulæ far outside the present domain of observation but obeying the same laws. As r increases up to just less than ct, V increases up to just less than c, according to the velocity distance proportionality. We are not extrapolating Hubble's law in daring fashion; we are relying on fundamental principles, whose implications within the present domain of observation are confirmed within that domain.

A system of particles moving in accordance with the above laws continues to disclose no preferential selection of a particular frame of reference. Hence in accordance with the view of gravitation expressed above it is a natural system. To move in any other way is possible; but if any one particle moves in some other way, so must some other particle, so as to neutralise the disturbance caused by the new motion of the first particle and thus continue to frustrate the selection of a particular frame of reference as special. We usually call this reaction of one particle's motion on another's "gravitational attraction," but the "force" thus introduced is a mere description of the totality of relevant motions. The above scheme of motions is one way in which, for the totality of particles in the universe, the concealment of a preferred

frame of reference is for ever complete; it is the simplest such scheme compatible with the idealisation to a system of particles in which velocity is correlated with position. We must regard the various departures of the actual portions of the actual universe from the ideal scheme—the rotations, the tidal distortions, the spiral forms and the elliptical flattenings—as all embroiderings on the simple ideal scheme which so adjust themselves that again no frame is preferred. Gravitation is another name for a succession of motions. To specify a set of such motions compatible with the non-existence of a preferential frame is equivalent to describing a gravitational field for the cosmos. We began by *assuming* rectilineal uniform motions for the particles of our system. We now see that such a set of uniform motions is a possible set of *actual* motions, which will perpetuate themselves. From the point of view of action at a distance, we may say that each particle is the centre of the system as viewed from itself, and so each particle is exposed to the symmetrical action of all the other particles, which cancel out. All the particles, being at rest in frames which are in uniform relative motion, have zero relative accelerations. Thus the state of uniform relative motion for each pair of particles is a sort of base-line gravitational field for discussing the universe. The system acts as a natural gravitational shield. When the "hydrodynamical" idealisation is replaced by a statistical idealisation, accelerations appear save for those special particles which in their own frames are still central. This allows a far more extended discussion of gravitation on the large scale, and allows us to trace the careers of all the particles from $t = 0$ to $t = \infty$, to predict the existence of condensations, to find their structure, and to obtain explanations of such phenomena as the "K-effect," the cosmic rays and the cosmic cloud. But I have no time to enter on it here.

Consider now a nebula moving with nearly the speed of light. If we record an event on this as happening, in our reckoning, at t, it will be recorded by the observer on that nebula as happening at the time $t' = t(1 - V^2/c^2)^{\frac{1}{2}}$, which will be very small. The age of the universe to this observer is very small, in fact arbitrarily small, for V is arbitrarily near c.

Hence this nebula must be in a very early stage of evolution. This effect is in addition to the effect of our actually viewing it at a later time owing to the finite time of light-travel. For this nebula, very little time has passed since "creation." It will be in a stage of evolution comparable with that we ourselves were in at time t' by our own scale. For the distant nebulæ the whole universe appears confined within a very small sphere, of radius ct', and it has accordingly had very little time in which to run down. Reckoned by it, at the event we reckon as t, the degree of run-downness of any portion of its observed universe is very small, whilst for us at the same event it is considerable. And reciprocally, in the world-wide "present" in which the distant observer ultimately will place the events we ourselves are now experiencing, he will assign more entropy to the world than we now do. It follows that the measure of the degree of run-downness of the universe at any given event is a purely subjective measure, depending on the observer who assigns that measure. Entropy and age go together, and both are subjective. Every observer's experience includes events arbitrarily close, in their local reckonings, to "creation" and so corresponding almost to the start of the world. We may say that the event of creation, as estimated by observers near the confines of the visible universe, is only just a thing of the past. In the limit, on the inaccessible unobservable boundary itself, creation is occurring in our "now." That singularity which in our local experience, in our past, we call creation, re-occurs now at distance ct from us. From one point of view, creation was one event; but its location in time is ambiguous. The state of *being first given* is being now realised at a distance of about 2×10^9 light-years. There, to us, time stands still. There the universe is enjoying its early local history. But if so, there comes no end in time to the world as a whole. As soon as we admit an infinite nebular population to the world—and a finite population would certainly imply the existence of a meaning to absolute position in space and absolute motion in space—we encounter all speeds up to that of light and we come upon an endless sequence of all but fresh beginnings. The universe is a continuing system. Each separate

portion, each local system, obeys the second law of thermodynamics, but there is no sense in which the world as a whole can be said to have run down, and, accordingly, to be, as a whole, running down.

Let us survey the ground we have traversed. We have been concerned, amongst other things, with an examination of the various ways in which the second law of thermodynamics might be applied to the whole universe. We have seen that conventional applications of it break down at the outset. The natural sequence of the nebular motions considered as a collection of moving points is such that the universe is passing from a more probable distribution to a less probable distribution. We saw that it acts as its own sorting demon. We saw that every system has a natural time-zero dividing its phase of expansion from a hypothetical phase of contraction, that if a system is first *given*, it is enormously probable, almost certain, that the epoch of being first given coincides with the natural zero ; and that accordingly it is overwhelmingly probable that any actual observation made on the system—made inevitably later than the moment at which it was first given—will disclose it as an expanding system. This is in accordance with the observed state of the universe. Further, we found no reliable evidence of events in the universe earlier than the time-zero, in accordance with the probabilities. We concluded that the universe was, for us as observers, once first given, that this state of affairs is indistinguishable from saying that there was a creation, and the universe was created in accordance with the probabilities, that is, it was not an exceptional system at the moment of creation. If it had to be created at all, then our universe is just the sort of universe we should expect. This creation is located for us, in our local experience, about 2×10^9 years ago. But when we paid attention to different observers' reckonings of time, we saw that this estimate is purely subjective. No absolute meaning would attach to saying that 2×10^9 years have " elapsed " since creation. No unique meaning can be attached to the phrase " the age of the universe at a given event." We then saw that the simplest idealisation of the universe gave a system of particles in motion

which naturally possessed a " gravitational field," in the usual sense of the term, equal at each particle to zero, this being merely the embodiment in a set of motions of the featurelessness of constructed space. Further, the system contains examples of every velocity up to that of light. Hence it contains local reckonings of the age which are arbitrarily small, counted from the time-zero. This is indistinguishable from saying that creation is ever-present on the confines of the observable universe, and that the universe is a perpetuating system, ageing everywhere, but always containing experiences arbitrarily young.

We have thus seen that Joule was right in dwelling on the connection between motion, gravitation and thermodynamics. The methods of probability applied to the whole universe predict, however, that it is disobeying what are usually considered to be the consequences of the second law of thermodynamics in two distinct ways : in the first place, considered as a system of sub-systems as viewed from any one of them, it is becoming more and more specialised instead of more and more mixed up ; and in the second place, it always contains constituents, in the present experience of any given constituent, which have proceeded on the evolutionary path an arbitrarily small distance. True as it is that the entropy of any limited portion of the universe is increasing, this statement does not justify the inference of a heat death for the universe. The universe is not, as a whole, running down. May I humbly repeat Joule's words : " I do assure you that the principles which I have very imperfectly advocated this evening may be applied very extensively in elucidating many of the abstruse as well as the simple points of science, and that patient enquiry on these grounds can hardly fail to be amply rewarded."

III.—The Mechanism of Ionogenic Reactions.[1]

By R. A. OGG, Jr.,[2] and M. POLANYI.

Communicated by Professor A. LAPWORTH, F.R.S.

THE adiabatic mechanism proposed by London [3] appears to account satisfactorily for the activation energies observed in the case of interchange reactions involving univalent atoms and homopolar molecules. This theory is however inadequate to deal with a large group of reactions which we wish to designate by the term "ionogenic." These are reactions involving the appearance or transfer of electric charges, i.e. in which an atom initially bound by a homopolar linkage passes into the ionic state. We wish to discuss here the mechanism and especially the activation energy of various types of ionogenic reactions.

IONIC INTERCHANGE REACTIONS.

Ionic interchange reactions constitute a type of ionogenic reaction involving a transfer of electric charge. The specific cases considered are substitutions of organic halides by halide ions, as for example :—

$$I^- + R_3CCl \rightarrow ICR_3 + Cl^- \quad . \quad . \quad (1)$$
$$I^- + R_3CI \rightarrow ICR_3 + I^- \quad . \quad . \quad (2)$$

[1] The essential features of this communication have been previously presented by one of the authors (M. Polanyi) in addresses given before the respective chemical societies of the University of Liverpool, Oxford University, University of Bristol, and University College of London.

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[3] F. London, *Probleme der modernen Physik* (Sommerfeld Festschrift) 104, Leipzig, S. Hirzel (1928) ; H. Eyring and M. Polanyi, *Z. physik. Chem.*, **12B**, 279 (1931) ; H. Eyring, *Jour. Am. Chem. Soc.*, **53**, 2537 (1931).

(Reactions of type (2) comprise racemisations of optically active organic halides by the corresponding halide ions.) Such reactions have been studied mostly in acetone solution, and are attended by activation energies of the order of 15 to 25 kilocalories per mole.

The general procedure is to find an intermediate configuration (transition complex) formed from the ion and alkyl halide which is capable of spontaneous dissociation into either the initial or the final state. The smallest energy increment necessary to produce such a complex is taken as the activation energy. General considerations show that in reactions of type (2) the transition state is symmetrical, i.e. the carbon and halogen nuclei lie evenly separated on a straight line, with the bonds of the carbon substituents in a plane. For reactions of type (1) the nuclei are colinear but the complex is of course unsymmetrical.

Most satisfactory agreement with experiment is afforded by a non-adiabatic mechanism. It is assumed that the identities of the ion and of the alkyl halide are preserved in the transition state, and that the reaction takes place by an electronic rearrangement such that the ion loses its charge and becomes bound to the carbon atom, while the halogen atom becomes a free ion. The transition probability is large only at the intersection of the potential energy surfaces for the initial and final states. Qualitatively, the activation energy arises from the fact that the ion has a larger effective radius than the atom, and hence that the carbon-halogen bond must be sufficiently elongated to accommodate the change of the halogen atom into an ion.

A more nearly exact treatment consists in constructing the appropriate energy surfaces and finding the lowest point of intersection. The Morse function is used for the carbon-halogen bond, and a simple approximate potential function for the interaction of the halide ion and carbon-halogen dipole. Additional contributions to the energy arise from the work necessary to force the bonds of the carbon substituents into a plane (steric effect) and from that required for the alkyl halide molecule to penetrate the solvation shell of the ion.

Activation energies for the reactions of halide ions with methyl halides have been calculated in accord with the above principles, and it appears that the results are also essentially valid for higher alkyl halides. While the theoretical values are necessarily only approximate, the agreement with experiment is satisfactory, both as regards the actual magnitude of the activation energies and their trend with the series of halogens.

Atomic Interchange Reactions of Alkali Metals.

A second type of ionogenic reaction involves the appearance of electric charges, and comprises atomic interchange reactions resulting in the formation of ionically bound molecules. The most important examples are the vapour phase reactions of alkali metals, chiefly sodium, with halogen ("X") compounds, yielding an alkali halide as one product. We wish here to consider especially the reactions with alkyl halides,

$$Na + RX \rightarrow NaX + R \quad . \quad . \quad . \quad (3)$$

but the principles adduced are applicable also to reactions with other halogen compounds.

Such reactions as (3) are known to be attended by small but appreciable activation energies. It is known that the alkali halides in the vapour state are ionically bound and that the corresponding atomically bound molecules have a very small dissociation energy.[1] If the above reactions were to proceed as purely atomic processes resulting in atomically bound alkali halide molecules (which would eventually lose energy and fall to the ionic state) they would be highly endothermic in the intermediate stage, and hence would possess large activation energies. This is definitely contrary to experimental facts. It appears that the transition to the ionically bound alkali halide molecule which renders the reaction energetically possible must occur while the reacting system is still in the intermediate configuration.

We wish to propose for such reactions a mechanism similar to that given above for ionic reactions. The inter-

[1] K. Sommermeyer, *Z. physik*, **56**, 548 (1929).

change process is pictured as taking place by a radiationless electronic transition yielding an alkali metal ion and halogen ion, thus setting free the alkyl radical.

$$(\mathrm{Na\ X} - \mathrm{R}) \rightarrow (\mathrm{Na^+ X^- R}) \quad . \quad . \quad (4)$$

As in the previous case the reaction occurs at the crossing of the respective energy surfaces. The elevation of the lowest point of intersection above the initial state gives the activation energy, which as before is due essentially to the increase in diameter of the halogen atom on becoming an ion.

The energy of the state represented by the left-hand side of (4) is the homopolar energy of a triatomic system. Its expression reduces simply to the potential function for R — X since the homopolar binding between Na and X and probably also between Na and R may be neglected. The energy expression for the state on the right-hand side of (4) is additatively composed of two potential functions for $Na^+ X^-$ and $X^- R$ respectively. The first of these may be adequately approximated in the relevant region from spectroscopic data. Sufficient information about the second may be deduced from the general physical principles governing interatomic forces.

Using the appropriate energy functions, the configuration for which the energy of both states is equal and a maximum is readily found. The amount by which this energy value exceeds that of the initial state is taken as the activation energy of the reaction. Results obtained in this fashion are in satisfactory agreement with the experimental data on reactions of sodium atoms with alkyl halides.

The essential similarity of the mechanisms proposed for ionic interchange reactions and the atomic interchange reactions of alkali metals affords an explanation of the parallelism previously pointed out between these two types of reaction.[1] In both cases when reactions of a given series of alkyl halides (containing the same halogen) are treated by the above methods, it is found that the respective activation energies are in the order of the energies of the corresponding carbon-halogen linkages. That is, the bond strength appears

[1] N. Meer and M. Polanyi, *Z. physik. Chem.*, **19B**, 164 (1932).

to be the prevailing factor in the activation energy. This is apparently in agreement with experimental fact: the order of reactivities of alkyl halides is the inverse of that of the corresponding restoring forces (derived from Raman spectra) of the carbon-halogen linkages attacked by either an ion or a sodium atom.

ELECTROLYTIC DISSOCIATION.

A third type of ionogenic reaction is the unimolecular dissociation of a homopolar molecule into ions. An example is the dissociation of phenyl-methyl-chloro-methane into chloride ion and the corresponding carbonium ion in liquid sulphur dioxide.[1]

It appears that an electrolytic dissociation might involve a true activation energy (i.e. in excess of the endothermicity of the reaction) in somewhat the same fashion as the reactions previously discussed. The reaction is considered to take place by an electronic transition yielding two ions, and such a process might well involve an increase in the energy of repulsion. In the example mentioned, the increase in effective diameter of the chlorine atom attending the change into a chloride ion is probably considerably greater than the decrease in the diameter of the carbon atom as the radical becomes an ion. That is, a preliminary extension of the carbon-chlorine bond might be necessary to accommodate the change to the ionic state, and the corresponding work required would appear as activation energy. Unfortunately, experimental data regarding such processes is as yet so meagre that theoretical considerations must be regarded as purely speculative.

In conclusion, the above discussion is intended to convey briefly the qualitative principles underlying the theory of the mechanism of ionogenic reactions, and no attempt has been made to explain the detailed methods of applying these in a more quantitative fashion. The detailed quantitative treatment and numerical results for various reactions are to be published shortly.

[1] E. Bergmann and M. Polanyi, *Naturwiss.*, **21**, 378 (1933).

IV.—On the Mechanism of Ionisation of Hydrogen at a Platinum Electrode.

By J. Horiuti and M. Polanyi.

Communicated by D. C. Henry, M.A.

When hydrogen containing an abnormally high fraction of diplogen is brought into contact with normal water in the presence of platinum black, the diplogen is quickly exchanged for haplogen.[1]

Though the electrolytic separation of the hydrogen isotopes indicates that there is an appreciable difference in the rate at which the two different isotopes are discharged at an electrode, and that it is, therefore, to be assumed that the rate at which they are ionised is also different, the principles underlying the ionisation process must be the same for both. Any explanation of the ionisation of diplogen will, therefore, throw light also on the ionisation of hydrogen.

Our first qualitative experiments have shown that the ionisation rate of diplogen is greatly influenced by the nature of the solution with which the hydrogen is brought into contact. From this effect we concluded that the process determining the rate of ionisation was not the splitting up of the hydrogen molecules, which cannot be appreciably influenced by the nature of the liquid phases, but the transfer of the adsorbed D-atoms into the solution as D^+ ions.

The experiments carried out more recently have proved that in our earlier work the catalyst was partially poisoned by CO which was present in the hydrogen.

[1] J. Horiuti and M. Polanyi, *Nature*, **132,** 819, 1933; **132,** 931, 1933. Bonhoeffer and Rummel, *Naturwiss*, **22,** 45, 1934. " Haplogen " is the name proposed for the ordinary hydrogen of mass 1, while the mixture of the two isotopes is called " hydrogen."

It is convenient to have the platinum black in a partially poisoned state, because otherwise the reaction rate is in most cases so large that it cannot be measured, since the diffusion is not rapid enough to cope with ionisation. However, the poisoned catalyst is not suitable for quantitative studies because the degree of poisoning is not sufficiently constant. Our new experiments were, therefore, made on an unpoisoned catalyst, with hydrogen purified by passage through a palladium thimble.

The only liquid found until now in which the ionisation rate on unpoisoned platinum is slow enough to be the rate determining factor, is alcoholic potassium hydroxide.[1] In the other solutions used with unpoisoned catalyst the ionisation is so rapid that the rate determining factor is the mechanical diffusion of the gas to the catalyst in the solution.

In the experiments recorded below a solution of 0·07 N KOH in 98 per cent. alcohol + 2 per cent. water was used and 0·03 g. of platinum black (prepared in the same way as in previous experiments) was employed.

In Table I. the data obtained at 0° C. are collected. The rates of ionisation are expressed in terms of first order reaction constants

$$k = \frac{1}{t} \ln \frac{C_0}{C_t}.$$

The justification for this constant is given directly in the example of the series Nos. 5, 9, 11. Further confirmation can be derived from the consistency of the data thus presented.

The comparison of experiment No. 1 with Nos. 5, 9, 11 which are made at equal hydrogen pressure, shows clearly the strong decrease of the ionisation rate caused by the addition of potassium hydroxide to the alcohol. The effect is really even larger than is indicated by the data of the table, because the ionisation velocity measured in the neutral alcohol was determined by the rate of diffusion, as could be concluded by

[1] It has been already reported in our earlier communications that such solutions have the strongest depressing influence on the ionisation rate.

TABLE I.

To show effect of

(*a*) Addition of KOH to the solution.
(*b*) Variation of time.
(*c*) Variation of pressure of the hydrogen.

No. of Experiments.	Solution.	Time, min.	Pressure of Hydrogen, mm.	k min.$^{-1}$.	$\sqrt{p}k$, Hgmm$^{\frac{1}{2}}$ min^{-1}.
1 .	98% C_2H_5OH + 2% H_2O	12	140	$0{\cdot}024^{1}$	$0{\cdot}28^{4}$
2 .	0·07/N KOH + 98% C_2H_5OH + 2% H_2O	45	175	$0{\cdot}0010^{0}$	$0{\cdot}013^{2}$
3 .	,,	70	32	$0{\cdot}0021^{4}$	$0{\cdot}012^{1}$
4 .	,,	70	312	$0{\cdot}0070^{0}$	$0{\cdot}012^{4}$
5 .	,,	70	146	$0{\cdot}0010^{9}$	$0{\cdot}013^{0}$
9 .	,,	120	144	$0{\cdot}0010^{8}$	$0{\cdot}013^{0}$
11 .	,,	240	144	$0{\cdot}0009^{7}$	$0{\cdot}011^{6}$

Mean for the potash soln.: 0·0125.

experiments on the influence of the hydrogen pressure to which we refer below.

The experiments in Table I. show very distinctly that the first order reaction constant varies with the pressure of hydrogen. As can be seen from column 6 of this Table and from Fig. 1, this variation can be represented as inversely proportional to the square root of the pressure [1]

$$k \sim p^{-\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

[1] Note added in proof on 11th May, 1934. Further experiments, which have been made since this paper went into print, have confirmed the inverse proportionality of K to the square root of the pressure of hydrogen.

Proportionality of k to $p^{-\frac{1}{2}}$ arises if the hydrogen is in the atomic state when passing the top of the activation barrier[1]

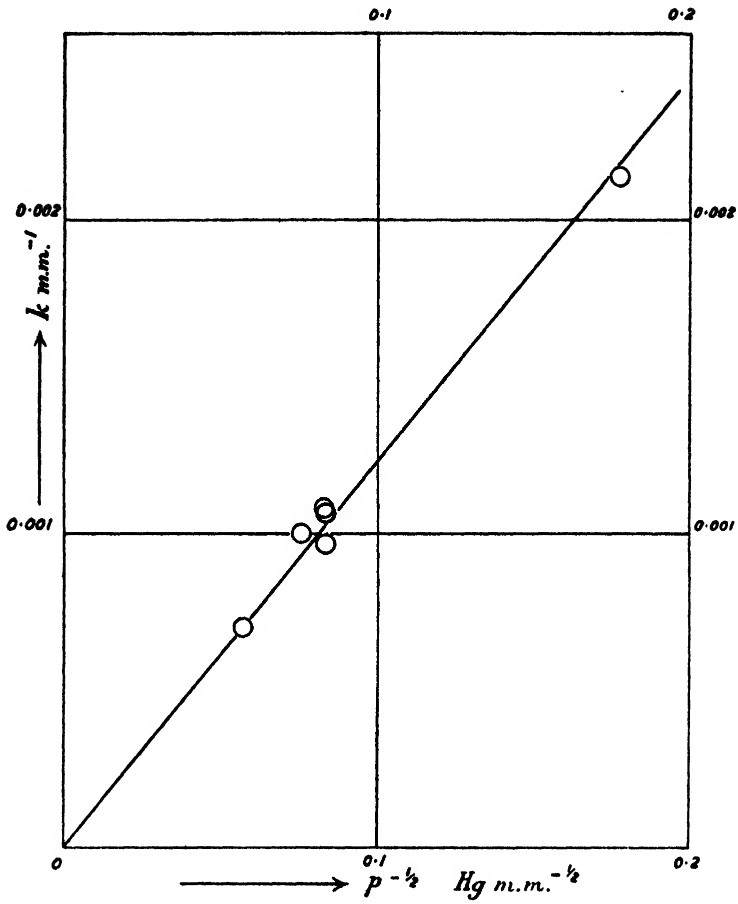

FIG. 1.

This conclusion holds, however, only if the height of the activation barrier is independent of pressure, *i.e.* independent of the change in the electrode potential which accompanies

[1] The "atomic state" to which we refer here is characterised by the statistical independence of the atomic co-ordinates. Therefore proportionality of the reaction rate to $p^{-\frac{1}{2}}$ shows again that the rate determining process is not the dissociation of hydrogen molecules since in such a process the atomic co-ordinates are not independent of one another.

the variation of pressure. We wish to consider this condition a little more closely.

The electrode potential ϵ has the form

$$\epsilon = -\frac{RT}{2F} \ln p + \text{const.} \quad . \quad . \quad (2)$$

and if we assume the equation of Erdey, Gruz and Volmer,[1]

then $$k \sim p^{-1} C_D e^{-\frac{A+\alpha\epsilon F}{RT}}, \quad . \quad . \quad . \quad . \quad (3)$$

in which A is the activation energy and C_D might, in extension of the authors' views, be taken to denote the "activity" of the D-atom in the adsorbed state. We have,

$$C_D \sim p^{\frac{1}{2}}. \quad . \quad . \quad . \quad . \quad (4)$$

By combining equations (3) and (4) we find

$$k \sim \frac{1}{\sqrt{p}} e^{-(A+\alpha\epsilon F)/RT}.$$

Hence from equation 1 the exponent must be constant. Therefore since $\epsilon \sim \ln p$ we see that α must be zero.

$$\alpha = 0. \quad . \quad . \quad . \quad . \quad (5)$$

As Frumkin [2] has pointed out there exists for the reverse reaction, *i.e.* the discharge of the ions on the electrode surface, a complementary coefficient α', connected with α by

$$\alpha + \alpha' = 1. \quad . \quad . \quad . \quad . \quad (6)$$

From (5) it follows that,

$$\alpha' \approx 1. \quad . \quad . \quad . \quad . \quad (7)$$

Bowden has obtained from the measurement of over-voltage for platinum $\alpha' = 0{\cdot}75$, when the electrode is fresh, falling to $0{\cdot}30$ on prolonged electrolysis.[3]

[1] *Zeitschr. f. phys. Chemie*, A., **150**, 203, 1930.
[2] A. Frumkin, *Zeitschr, f. phys. Chem.* (A.), **164**, 121, 1933.
[3] *Proc. Roy. Soc.*, **126** (A.), 107, 1929.

Our own experiments also may be taken to indicate that α is not exactly zero, since the strong depressing influence which the addition of potassium hydroxide to the alcohol has on the reaction rate, could then be attributed to the more negative values, which the electrode potential assumes in alkaline solutions.

It should be remarked here that in no solutions other than alcoholic potassium hydroxide could we ever detect an influence of pressure on the (first order) reaction rate.

This was one of the reasons which led us to conclude that in those solutions the rate determining factor was not the ionisation process, but the diffusion of the gas to the catalyst in the solution.

Table II. and Fig. 2 shows the dependence of the ionisation

TABLE II.

Temperature Dependence of $\sqrt{p}\,k$.
Solution : 0·07/N KOH + 98 per cent. C_2H_5OH + 2 per cent. H_2O.

No. of Experiments.	Temperature, °C.	Pressure, mm.	Time, min.	$\sqrt{p}\,k$ Hgmm.$^{\frac{1}{2}}$ min.$^{-1}$.
6 . .	18·1	139	60	0·036^{9}
7 . .	−13·1	11	480	0·0052
8 . .	18·4	146	60	0·036^{0}
10 . .	16·6	138	60	0·032^{3}
The mean of (2, 3, 4, 5, 9 11)	0°	—	—	0·0125

rate on temperature. The ionisation rate shows an increase with temperature which follows Arrhenius' law. The overall activation energy is 10,200 cals.

Our experiment values for k may be expressed by the equation :—

$$k = \frac{1{\cdot}7 \times 10^{6}}{\sqrt{p}} e^{-\frac{10200}{RT}} \text{ min}^{-1}. \qquad . \quad . \quad (8)$$

To this empirical formula we may give the following interpretation :—

$$k = \frac{N_a \nu e^{-\frac{A}{RT}}}{2N_{H_2}} \quad . \quad . \quad . \quad . \quad (9)$$

wherein : N_a is the number of adsorbed hydrogen atoms (which is taken to be proportional to the number of adsorbed

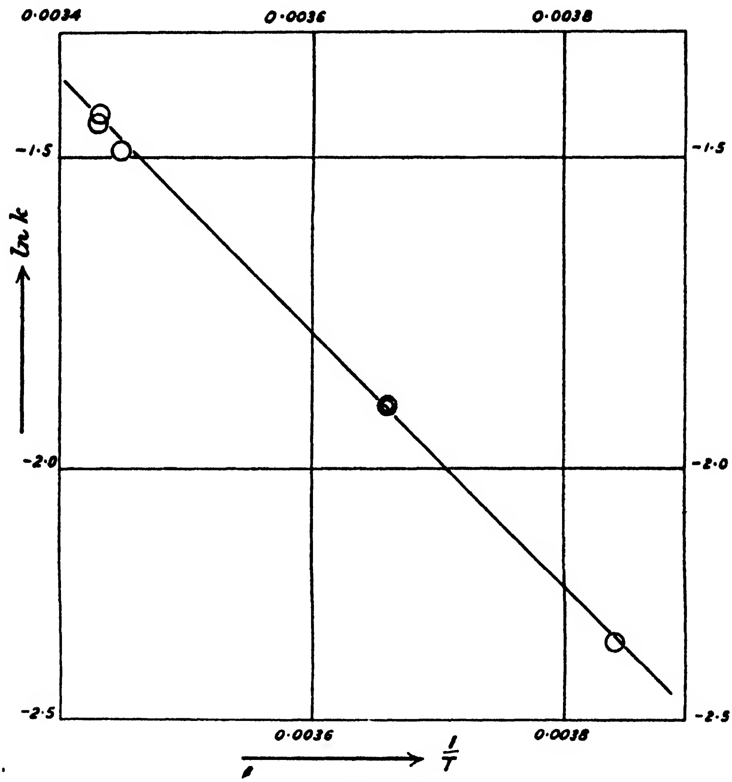

FIG. 2.

diplogen atoms) ; ν is the temperature independent factor of the ionisation rate ; A is the activation energy of this process, and N_{H_2} is the number of hydrogen molecules in the gas phase.

Furthermore, if we assume that the gas laws hold in the adsorbed state,

$$N_a = N_H \frac{\delta\sigma}{v} e^{\frac{Q_a}{RT}}, \quad . \quad . \quad . \quad (10)$$

where N_H denotes the number of hydrogen atoms in the gas phase, Q_a the adsorption heat of atomic hydrogen, δ the "thickness" of the electro-chemically active layer, *i.e.* the vibrational amplitude of the adsorbed atoms, σ the surface of the catalyst, and v the volume of the gas phase.

N_H we can express by the dissociation heat D and the factor K according to the reaction isochore:

$$N_H = \sqrt{N_{H_2}K} \, . \, e^{-\frac{D}{2RT}}, \qquad . \qquad . \qquad . \quad (11)$$

so that (9) ultimately takes the form,

$$k = \frac{1}{2}\sqrt{\frac{K}{N_{H_2}}} \, \frac{\delta\sigma}{v} \nu e^{\frac{-\frac{1}{2}D+Q_a-A}{RT}} \qquad . \qquad . \qquad . \quad (12)$$

From this we conclude firstly that the overall activation energy of 10,200 cals. measured in our experiments is to be equated with

$$-\tfrac{1}{2}D + Q_a - A \qquad . \qquad . \qquad . \quad (13)$$

As Q_a is probably only a few calories larger than $\frac{1}{2}$D, we conclude that the true activation energy of the ionisation process A is only slightly larger than the overall activation energy of 10,200 cals.[1]

[1] For the temperature coefficient of overvoltage on bright platinum Bowden (*Proc. Roy. Soc.*, **126**, 107, 1929) derived as the activation energy of ionisation 7000 to 9000 cals., depending upon the state of activity of the surface.

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V.—The Tongue as a Primitive Sense Organ.

A Lecture delivered by David Katz, *formerly Professor of Psychology at the University of Rostock, to the Manchester Literary and Philosophical Society on 8th May,* 1934.

This lecture is a contribution to developmental psychology. Psychology can be considered as a part of biology. From biology the idea of evolution has entered the field of modern psychology. Modern psychology therefore does not confine itself to describing how the mind is working at present, but it also tries to find out the steps in its evolution. The main parts of developmental psychology are animal psychology, child psychology and folk psychology. But from general psychology too we can approach the problem of how consciousness has developed. As to the evolution of sense-perception psychologists have always dealt with the question of the succession in which the different sensations such as hearing, seeing, smelling and so on have entered the mind and how in the individual fields of sensation the various qualities have developed. Just as we distinguish in geology many layers of different age and make use of these layers to get information about the geological evolution of the earth so in the mental life of men too there exist, as it were, layers of different age from which one may get data explaining the evolution of the senses. I should like to illustrate my meaning by the following examples. You all know that we can perceive the whole variety of colours only by the centre of the retina. If we move colour stimuli from the centre of the retina to the periphery, red and green disappear first, and when we go still farther to the periphery blue and yellow too no longer exist. The extreme periphery of the retina is absolutely colour-blind ; it only can perceive black and white.

These experiences, as well as others, seem to give evidence that in the life of animals the so-called black-white-sense has developed first, then the yellow-blue-sense and at last the perception of green and red. If we wish to know how our animal-ancestors perceived the world by vision the only thing we have to do is to eye our surroundings with the periphery of the retina. Our ancestors must have seen the world like a copperplate engraving in black and white. I shall give another example. The perception of shapes is very imperfect on the periphery of the retina. We can hardly recognise by the periphery even well-known figures, but we are very sensitive to the slightest motion. We are nearly as sensitive to motion there as we are in the centre of the retina. This seems to prove the fact that the perception of motion has developed at a much earlier date than the perception of motionless figures. This statement gets full confirmation in animal psychology. I am contented with these two examples. They make quite clear what I wanted to demonstrate, that one can approach problems of evolutional psychology from general psychology. What I have to say about the tongue as a primitive sense organ is in the same sense a contribution to developmental psychology.

However different the hypotheses concerning the origin and the evolution of life may, be they all agree on one point, namely, life can only have originated and developed in water. It was at a rather late date that life adapted itself to the conditions given on dry land and in the air. I suppose that developmental psychology has not yet fully realised the importance of this process of the body going dry (Trockenlegung) in relation to our instincts and in relation to the changes of our sense organisation. The physiologists have always paid full attention to the water-economics (Wasserhaushalt) of our body which as you know consists of about 60 per cent. of water. Psychologically our connection with water is quite manifest in the enormous strength of our need of water in its different forms. It is known that deficiency of water is much more difficult to tolerate than deficiency of food. To die of thirst is much more appalling than to die of hunger. Therefore, the penalty of thirst and not of hunger was put

on Tantalus. There must be good watchmen to watch over the water economics of our body. It must be quite different with animals which live in water. They could not, and cannot lack water. For this reason there was no necessity for an equipment by which to feel thirst. Such a necessity only arose when the animals left the water to live in the air. In this equipment the salivary glands play an important rôle and as a matter of fact one finds those glands only in animals living on land, not in animals living in water or in animals which, like the Cetacea, have returned to the water.[1] Animals living in water must have a sensorial equipment by which they are sensitive to the water surrounding them and are immediately warned if they are driven by chance into dangerous dry regions. Probably consciousness of the water-surroundings is given by the whole body surface. When animals left the water there was no further necessity for a sensorial equipment by which the moist surroundings could be perceived by the whole surface of the body. By the drying the slimy surface disappeared and with it the basis for the sense organs which could perceive wetness. This function was restricted then to a single organ, namely the tongue. The fact that fish can taste with the beaker-shaped organs in the outer skin furnishes indirect evidence to indicate that they are capable of perceiving water which contains taste material. F. E. Schulze's anatomical studies (1863) of these organs provided the first suggestion that they were connected with taste, and this view has since then been confirmed by experiments with fish.[2] According to Kiesow's experiments with children the taste organs tend to diminish in number during the life of the individual.[3] In early childhood those parts of the tongue and the pharynx which in adults are anaesthetic to taste are quite capable of taste sensation. An analysis of gustatory terminology among primitive people led Myers to the view that "the intimate connections between sensations of taste, touch and emotional tone, to which the vocabularies of primitive people bear witness, date back to a very early period of phylogenesis." [4]

It is generally assumed that the impressions given by the tongue have a near relation to the feeling of thirst and to the

regulation of the body's water supply. But what I have to emphasise is that the tongue is the only organ which gives us genuine impressions of moisture and of its contrary dryness. The tongue is in a certain sense the only organ which by its impressions immediately demonstrates that life is born in water. It is more than an illustration to say that the fish feels itself in water just as the tongue feels in the mouth. The tongue gives human beings born on land an immediate impression how water-animals may feel in their watery surroundings. I think that after these explanations it has become quite clear why I call the tongue a primitive sense organ. This hypothesis fits in quite well with the well-known behaviour of the new-born child. From the first day after birth the baby is engrossed in the business of sucking, and in this activity the tongue, with its sensory-motor functions, plays a particularly large part. Long before, and long after the grasping function of the hand has been fully developed the child still gets his information about the properties of objects by means of his tongue. For organisms living in water it is very easy to provide themselves with water, but there have to be special organs for providing the body with food. The organism had to be equipped with sense organs by which it got information about the presence or approach of food, either vegetarian or animal. The stimuli aroused by food might be chemical or mechanical ones. As to the mechanical stimuli, they might be represented by the sticky or slimy surface of plants or animals. Psychologists have up till now paid hardly any attention to this kind of stimulation in the field of obtaining food. Mechanical stimuli of this kind probably are much more important than has been recognised. It is a heresy to express my opinion that they are more important than the four qualities, sour, salty, sweet and bitter, with which the text-books of psychology are particularly concerned in the field of taste. However important these mechanical stimuli may be they can only be effective by getting immediate contact with the sensitive part of the body. What I have called mechanical perception of food does not work at a distance. As to chemical stimulation by the food the taste organs can only be stimulated by extremely small

particles of the food which are dissolved in the water. The sense of smell developed to full perfection only after animals left the water. The sense of taste is a specific chemical sense. Furthermore the sense of taste is what I call a near-sense because it has to have contact with the chemical stimuli without the interference of any medium. The physiologists will not deny that the near-senses developed before the far-senses. Once more the tongue is proved to be a primitive sense organ because of its chemical stimulation and its character as a near-sense. The tongue is the only organ which is stimulated only through a liquid medium ; no solid body can be tasted by the tongue. If it is not liquid it can only be tasted when it is dissolved in the saliva. The old principle of chemists, " corpora non agunt nisi fluida " still holds true for the sense of taste. Many chemical solutions which have taste give it by ionisation. Physiologists who have done research in the field of taste have therefore tried to make clear how the special qualities of taste depend upon ionisation.[5] In accordance with these ideas the tongue has an astonishing sensitivity to an electric current. There is no other sense organ which has so marked a sensitivity. This is another point which I should like to illustrate.

Now I consider it my task to give more details about the two problems I have mentioned, first the feeling of moistness and dryness by the tongue, and second the stimulation of the tongue by an electric current. The second is generally called the problem of electric taste.

Starting with the first problem, I should like to remind you of some simple facts of anatomy and physiology to which up till now little attention has been paid by psychologists. Nearly the whole surface of our body is dry and is normally kept dry. Only those parts where there are sweat glands get wet under certain circumstances. The tongue has no sweat glands. As to the dryness of the body surface there is only one exception, namely the sclera of the eyes. The sclera is kept moist by the secretion of the tear-glands. In contrast to this dryness of the body surface all the surfaces of the inner part of our body are moist. This is also true of the entrance to the inner body, the different parts of the

mouth and the mucous membrane of the nose. Now it is a fact that normally neither the dryness of the outer surface nor the moistness of the inner surface of the body is felt in a specific manner. Let us first consider the impressions we get from the inner part of the body. If you drink a glass of water you do not feel wetness in your œsophagus or stomach. All you feel is warmth if the drink is warm or coldness if the drink is cold. Let us consider the impression of the outer surface of the body. First of all you never feel its normal state of dryness in a specific way. If you do not move yourself you may have a certain impression of warmth or coldness and a certain impression of touch but you do not feel dryness as a positive impression. Can we feel objective dryness and moistness of the sclera in a subjective way? The movement of the eyelid has the function of moistening the eye-surface and this movement is made when the eye becomes dry. But can we say that dryness and moistness of the eye-surface is felt as such? By no means. The objective dryness is felt only as a sort of painful pressure. We may compare the impression of dryness with that which we get if sand or powder enters the eye. It becomes quite clear that we have not a specific impression of moistness with the eye when we open the eye under water. All we experience then is a certain change of impression of touch and temperature which is probably related to sensations of the skin. The only part of the whole body whose natural state is that of moistness and which gives us the real subjective impression of wetness is the tongue. Will you be good enough to pay attention to the impression which you are getting at this moment from your tongue. If you do you will understand what I mean by the positive impression of moistness. This impression is given permanently. It seems not to be weakened as a touch impression is weakened if the stimulus is not changed. If you do not move one of your limbs, for example, your hand, you will not feel this limb very clearly, but you always feel the moistness of your tongue even if you do not move it within your mouth. It is for this reason that it would be quite incorrect to say that the impression of moistness at the tongue is nothing but a certain complex of touch. I

feel quite sure that the permanent impression of moistness given by the tongue plays a much more important rôle in the building-up of our so-called bodily "Ego" than has been realised up to now. This impression I dare to say, is much nearer to our Ego than others. It is connected with the fact that we touch many things with our hands which we never would touch with our tongues. The well-known fact that the size of things touched by the tongue is tremendously exaggerated may be connected with this phenomenon of nearness to the Ego.

We have to ask whether other parts of the inner mouth give this impression of wetness too, for instance the mucous membranes of the cheeks, the jaws and the roof of the mouth. I have made some simple experiments by which this question can be answered. With blotting paper I dried the different parts of the mucous membranes of the cheeks and the jaws —it is not easy to do this but with some practice you may be successful—having done so I felt a difference between the two objective states of dryness and wetness. But the difference is only related to pressure and temperature. The result is quite different if we use blotting paper to dry the tongue. It is not so difficult to dry the front part of the tongue with blotting paper to such a degree that even sugar or salt put on the tongue cannot be tasted because of the lack of solution of these substances. If we have managed this the objective dryness of the tongue is felt by a specific impression quite different from impressions given by other parts of the mouth made dry. The impression of dryness given by the tongue under these experimental conditions is a positive one. It is in absolute contrast to the impression of wetness which is given under normal conditions. Breathing with open mouth is another method of drying the different parts of the mouth. This method makes it quite clear, that under normal conditions a part of the soft palate gives the impression of moistness too. Whereas the normal impression given by the tongue corresponding to the normal physical state of wetness is the impression of wetness, it is of foremost interest that another part of our body not yet mentioned gives us under normal conditions the impression of dryness. This is a special

section of the pharynx. Almost without interruption that part of the pharynx where the œsophagus crosses the trachea gives the impression of dryness. Only at moments when we are drinking a fluid or swallowing saliva or immediately after that swallowing does the feeling of dryness at that part of the pharynx disappear. I dare say that it is only by this impression we really know what positive dryness is, just as only by the normal impressions of the tongue we really know what moistness means in a subjective sense. I present you the hypothesis that the tongue with the permanent feeling of moistness and the pharynx with its nearly permanent feeling of dryness form one sensory unit which, as a whole, plays an extremely important rôle in supervising the water economy of our body. It is well known that the impression of dryness localised at the tongue and the pharynx play an important rôle in regulating thirst, but I have to emphasise that even if we have drunk to full satisfaction we may periodically feel dryness in that part of the pharynx. This impression of dryness grows intensively, if we try not to swallow the secreted saliva as long as possible. If you make this experiment you will find that the impression gets tormenting, it is very like the feeling you get if you try to suppress breathing. Probably the secretion of saliva which takes place when there is nothing in the mouth which, by a conditioned or unconditioned reflex could stimulate the salivary glands, is only produced by the sensation of dryness given by the pharynx. The normal dryness felt by the pharynx has not the character of an order to us to drink.

The comparatively dry air moving over that part of the pharynx causes the sensation of dryness which is the real stimulus for the secretion and swallowing of the saliva. This dryness could be called false thirst, for it appears, as has already been said, even if there is no need of water for the body. Perhaps one could dare to propose the hypothesis that this swallowing of saliva is a sort of atavism from the old breathing by gills found in fish, the last remainder of that mechanism. The feeling of suffocation caused by suppressing the swallowing of saliva might be an argument for my hypothesis.

I feel quite sure that we should not speak of wetness or dryness at all if these phenomena were not perceived in the way described by the tongue and the pharynx respectively. If in a thought experiment you had to imagine dryness of a specific material, i.e. powder, and wetness of another material, i.e. water, what is given in your mind probably is the image of dryness and wetness in your mouth. Of course there may be some of you who imagine dryness and moistness by other parts of the body for instance by the hand. What I assert is that in most cases there is a sort of transfer of the images of wetness and dryness from the mouth to the presupposed other organ.

Some of you might be in opposition to what I said about the excellent position of the mouth for the perception of dryness and wetness. You may tell me that you can distinguish very well dry objects and moist objects only by touching them by the hand or the foot or by other parts of the body. This is true but in reality what is given to you in all these cases is nothing but a complex of touch impressions and impressions of temperature, warm or cold. Only by such complexes does the total impression of wetness or dryness arise.[6] We could speak about specific touch-temperature entities. It is not hard to prove this. Water is not felt with the hand if the hand is not moved. Only by movement can the specific complexes of touch and temperature which are judged as wetness be developed. On the contrary wetness can be felt by the tongue if there is no movement. For the tongue dryness and wetness is a static sensation, whereas for the hand it is a dynamic one. I should like to give still another formulation. Only the tongue is able to feel as it were the substance of water, whereas the hand feels water by the physical alteration which it produces in the field of touch and temperature. It is not too difficult to give an explanation of these differences. The physiological effect produced by water on the hand and on the tongue are quite different. If water is brought on the skin of the hand there is almost no alteration of the skin. There is no great absorption of water by the skin, but if we dry the tongue or wet it the physiological state of the tongue is altered. The surface

of the tongue has anatomically the structure of a sponge with numerous mucous glands. Probably the change in physical state of this spongy material produces the impressions of dryness and wetness. I think it would be absolutely false to say that sensations of dryness and wetness are nothing but certain impressions of touch. There are still other proofs for my argument that wetness or moistness can be perceived in a specific way only by the tongue. If we combine certain touch and temperature impressions in a specific way the hand gets a perfect illusion of touching wet objects, although there is no wetness at all.[7] No wonder, for the skin of the hand is not altered in a specific way by real water. But you will never succeed in giving the tongue the impression of wetness if you submit it to such a combination. If you put your hand in alcohol or other liquid which has similar physical qualities to water then you may have nearly the same impression which you get by water. But if you put pure alcohol on the tongue which has been dried before, you do not get the impression which is produced by water. The reason for this is, that alcohol has an effect on the surface of the tongue different from that of water. And finally I have to say that wetness and dryness perceived by the hand are by no means opposite as to their immediate impressions, but that they are felt as contrasts by the tongue. You immediately feel that they belong together as a pair of contrasting sensations.

The saliva is sticky because of a certain amount of mucin which it contains; it is by no means as fluid as pure water. The tongue perceives quite well the difference between the two mediums, if it is brought from saliva into pure water. We can alter the impression of the water by adding certain materials like gelatine and we may find out the threshold, which is just perceived if the amount of gelatine is increased. There is a long series of impressions concerning the liquidity which the tongue can distinguish from the most fluid things like water through materials like pap to dry materials like bread or chocolate. All these impressions have not yet been investigated although they are most important both in a theoretical and a practical sense; in a practical sense owing to the fact that the character of food is changed perfectly if

only its physical constitution is altered. We know since Pavlov that the quality and the quantity of saliva alters only with the physical constitution of material brought into the mouth, but psychologists have not yet paid attention enough to the accompanying impressions and their correlation with the physiological processes.

Is there anything to be learned from pathology in this connection? Some cases of syringomyelia are described by Feidelberg in which the sensations of wet and dry were definitely affected.[8] Unfortunately his findings cannot be applied uncritically to the present problems, because he holds that the experiences of wet and dry on other parts of the body are essentially the same as the wet and dry experienced on the tongue. Nevertheless in connection with one of the cases he reports that " the tongue was highly sensitive to touch, pain, cold and warm, but less sensitive to wet and dry," and this seems to support our view that wet and dry are not to be considered as complexes of touch and temperature. Our point of view would, of course, not hinder us from believing that disturbances in the impression of wet and dry could take place at other points than on the tongue. The fact that even the dry experience which serves to provoke thirst can be lost is clear from rare cases of cachexia hypophysipriva, in which thirst is completely lost, with the result that the patients stand in danger of death through lack of water in the body.[9]

Now, I have to leave this problem and I have to speak of what in my introduction I have called electric taste. Even boys know something about electric taste, they test the effectiveness of their small batteries by bringing the poles of the battery in contact with the tongue and they know that the positive pole is where there is a sour taste, the negative where there is a sort of bitter taste. A few remarks about the history of electric taste.[10] The first to describe the strange impressions given by touching the tongue with two metals which are combined seems to have been Sulzer. Volta realised the relations between these impressions and the electric current. Very soon it was found that the same current may produce taste on the tongue and a colour sensation on the retina. The investigation of the electric taste made

remarkable progress when the theory of electrolysis was applied to it. There have been two theories of electric taste. One theory maintains the effectiveness of the current on the taste-buds themselves. Another theory is that the electric current does not immediately stimulate the tastebuds but that it effects an electrolysis of the saliva and that the electrolytic products stimulate the tastebuds. It seems to me that both theories have to be combined. One experiment has been brought forward against the electrolytic theory. If a current passes through two individuals who are touching each other by their tongues the two individuals get different tastes at the same spot where their tongues touch, one getting a sour, the other getting a bitter taste. After these remarks I shall discuss my own experiments. They have been performed with the very simplest apparatus. You need nothing but a few small metal bars and some resistances. But even those can be replaced by human bodies which provide the resistances needed. We take two metals from a series of metals, two of which combined in an electrolyte produce an electric potential. Now for instance, I take carbon and zinc and combine them by means of a piece of copper wire. As an electrolyte we use our own saliva. At the moment I touch the tongue I get two different impressions, one at the anode, the other at the cathode. I describe the two impressions. First of all, there are taste-impressions, sour with a bit of salty at the anode, bitter and sweet at the cathode.[11] To the sour-salty taste there is added a component which usually is called metallic and at the cathode a component which in the literature has been called a chemical alkaline taste. The metallic taste has nothing to do with the fact that we used zinc as anode, for even if non-polarisable electrodes are used and no metals at all, we get the same metallic taste. The metallic taste is by no means a smell as some physiologitss think and it is not a sensation of touch.[12] Besides the qualities of the taste already recognised, sour, salty, bitter and sweet, there exist other taste impressions. Former authors have sometimes spoken of simultaneous and successive contrast existing in the sense of taste. Our experiments seem to demonstrate that the complex sour-salty is contrary to

sweet-bitter. Phenomenologically there is no evidence of this contrast. But the same applies for the contrast between red and green or blue and yellow. A contrast which is evident is that of the whole complexes given by the electrodes. The impression on the anode could be called brighter and the impression on the cathode darker. We can describe this difference in another way; there are subjects who call the impression at the anode lighter and at the cathode heavier. This is a very interesting contrast, which seems to show that the so-called intermodal qualities exist too in the sense of taste. Experiments have shown that what is called brightness in the field of vision has its parallel in other fields of sensation, for instance in the field of hearing and in the field of smelling.[13] Now our experiments make it clear that this difference stands in the field of taste too. We shall come back to these intermodal qualities. I now go on describing the impressions we get at the two poles. If we pay full attention to the impressions we find that there exists a burning or tingling sensation, which it is true is very weak, but it exists. The tingling is clear at the anode. We can compare it to the impression which we get from a vibrating tuning fork. I therefore should like to call it a vibratory sensation. We can get a similar impression if we put a drop of soda water on the tongue by means of a paintbrush. You all know this impression from the drinking of soda water. Just as the tingling sensation caused by soda water may be in connection with the secretion of the carbon dioxide so the tingling sensation at the electrodes may be caused by the small bubbles of gas which are produced at the poles. You get the tingling impression only after the current has been effective for a certain time. If we turn on the current only for a short time, let us say a second, we do not get the tingling but only the taste I have described. Probably the production of gas takes a certain time to become effective. This fact seems to show that we are right in supporting the electrolytic theory.

For a long time the so-called galvanic colour-sensation has been investigated. If an electric current passes through the retina a colour sensation is produced. If the current

flows from the nervous membrane to the rods and cones of the eye the field of vision gets brighter and the colours, blue and red, are produced; if the current takes the other direction the field of vision gets darker and the colours, yellow and green, are produced.[14] The contrast between the colours is correlated with the reversing of the current as is the contrast we found between the taste qualities dark and bright, or the contrast between the qualities sour-salty and sweet-bitter. In both cases we find one intermodal quality connected with the one direction of the current and the other with the reverse direction.

A few words about the physics and physiology of the electric taste. The tastes seem not to depend upon the metals used. For instance iron combined with magnesium gives a bitter taste, combined with carbon it gives a sour taste. A further proof for this independency may be seen in the fact that whatever combination we use we always get the threshold of the taste at the same intensity of the current. We may send the current through pure water into which the tongue is put, and even then we get the same impression. As to the smallest current which is effective I have found that under special conditions it is as small as 0·7 microamp., i.e. less than 1 millionth of an ampere. This is a very small value. I may give a more concrete idea of it. If I combine carbon and magnesium I have to include about 1 million ohms to get the threshold for a sensitive subject. Or I may introduce several individuals through whom the current passes. The current which has to be applied to stimulate the muscle of a prepared frog has nearly the same value. Finally, I should like to say that the current which is produced in the so-called electro-galvanic phenomenon is about one-tenth of the current which is effective at the tongue.[15] The electro-galvanic phenomenon refers to the fact that the human body itself produces electric currents if we hold two electrodes with both hands without any other electric source included. You see we can nearly taste the current which is produced by the human body itself.

There are big individual differences in electric taste. There are people who are very sensitive and others who are not.

We have a simple method of demonstrating such differences. We use one subject to produce the current by which the other is stimulated. In this circuit the same current stimulates both. Now we may find out which of the two has the lower threshold.

If we dry our tongues by means of blotting paper the electric current is no longer effective, even if it is much stronger than usual. Probably the inefficiency has to be explained by the fact that there is no longer in the taste-buds the amount of saliva which has to be electrolysed in order to stimulate the sense organs.

In the text-books of physiology and psychology it is said that the ventral part of the tongue as well as a certain part of the upper median part has no taste sensations at all. But it is quite obvious that taste sensations could be got by means of the electric current at these spots. Certainly they are not as distinct as in the other parts of the tongue, but they clearly can be proved to exist. For their demonstration it is better to move the electrodes on the surface of the tongue, than to let them rest on the tongue. This experiment seems to show that these spots too have sense organs, but normally they are not stimulated by taste-material.

By means of the electric current we may study a number of facts which cannot be studied so easily in the ordinary way. This holds true firstly for the study of the after-images of the sense of taste. The positive after-images of the bitter-sweet at the cathode are extremely strong, they often last for several minutes after the stimulation has ceased. They are so strong that one thinks, that the electrode contains real taste-material. They last much longer than the positive after-images of vision. At the anode the sour taste does not give such strong after-images. If at the anode we give the stimuli periodically with intervals which are not too long we get the impression of a lasting taste. As to the intensity of this impression it corresponds to the intensity which would be expected if the Talbot law were valid. The Talbot law was found in the field of vision. It reads as follows: If the retina is periodically stimulated by light the brightness of the impression is equal to that which we would get if the

whole light during a period were distributed equally over the whole of that period. It does not matter whether the periods are filled by equal or unequal subdivisions. The simplest way to demonstrate the meaning of this law is by a spinning disc divided radially into black and white parts. Let us suppose that we use the same disc for electric stimulation in such a way that for the white parts the current is turned on, and turned off for the dark parts or vice versa, then we always get the same impression of intensity. We therefore are right to speak of parallel laws. It is quite obvious that this law could not have been found by the former way of using taste-materials. It could only be discovered by means of the electric current.

Finally I should like to touch upon a curious taste impression which puzzled me for a long time. It sometimes happens that the roof of the mouth is lightly injured by a hard piece of bread. The fresh wound gives a faint taste of blood. But if one touches the healing spot with the tongue, one gets a new strange taste. This taste is identical with the taste of the anode. It is not probable that this taste is caused by any secretion of the wound. This I have proved by the following method. The described taste is not only given at a wound in the mouth, but at every other wound. Now I have found that the taste continues if a piece of paper moistened with water is placed between the wound and the tongue. The intensity of the taste is not even changed if the strip of paper is continually moved between the wound and the tongue. In this case it is impossible for any secretion of the wound to pass the paper and reach the tongue. But whence can the taste arise? The identity with the electric taste suggest that electric processes play their part in it. We know that healing processes are accompanied by electric processes. The wound itself is negative in opposition to its positive electric surroundings. Probably the current arising from this potential difference is the stimulus of the tongue. The strength of the taste, which is distinctly beyond the threshold, is a witness to the strength of the current. Further investigations will be undertaken to give more details about the origin of the electric current in the wound.

This paper aims at summarising some of the research I have undertaken in the Psychological Laboratory of the University of Manchester. I take this opportunity of expressing my profound gratitude to my friend, Professor T. H. Pear, for having granted me all possible facilities to perform my experiments, to the Authorities of the University, and to all those who have enabled me to continue my scientific work in this country.

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PROCEEDINGS OF THE MANCHESTER LITERARY AND PHILOSOPHICAL SOCIETY.

Obituaries.

Herbert Carrington, D.Sc., M.Sc.Tech., A.M.Inst.C.E., A.M.I.Mech.E., passed away at his home at Woodley on 4th July, 1933, at the age of 42.

Dr. Carrington served his apprenticeship at the National Gas Engine Co. Ltd., Ashton-under-Lyne, and Messrs. Platt Bros. Ltd., Oldham. He then returned to the National Gas Engine Co. as draughtsman and had a further short period with Messrs. Platt Bros. He was awarded a scholarship from the Oldham Technical School tenable at Manchester University, where he took his B.Sc. degree with first-class honours and was awarded a graduate scholarship.

He was then engaged on research work during the war in connection with the Royal Air Force. On the termination of hostilities he was thanked by the Chief of the Royal Air Force.

In 1919 he was appointed Assistant Lecturer in Mechanical Engineering in the Manchester College of Technology and in the University of Manchester. He was a recognised authority on the strength of materials and the author of many publications on this subject. For his research work in this connection he was awarded a Doctorate of Science by the Manchester University.

He was of a studious and quiet disposition and lived for his work.

D. S.

His Honour Judge F. E. Bradley, who died on 3rd September of last year at Eastbourne, had in the course of a very active life played in succession the parts of scientist and lawyer. Few men nowadays could boast of having successfully practised

one profession and established himself in another by the age of twenty-seven. He was born on 6th April, 1862, and educated at Manchester Grammar School and Owens College, where he studied chemistry from 1880 to 1882. For the next three years he worked in his father's laboratory, inventing and patenting improvements in various chemical processes. Among his patents was a process for cleaning and scouring silks, and a kiln designed to prevent the arsenic in coke from contaminating barley during the malting process. At the age of twenty-three, however, he decided to abandon what to many would have seemed a promising career, and, re-entering Owens College he proceeded with several distinctions to take a degree in Law. In 1889 he was called to the Bar and began practice in the Northern Circuit. In his new profession he maintained his academic connection by holding the offices of Lecturer in Equity at Liverpool and tutor in English Law at Manchester University. His numerous works on legal subjects occupied most of his leisure, but he maintained throughout life an interest in scientific matters, which became intensified in his later years.

W. B. W.

It is with deep regret that we record the death of Dr. Donald Elms Core.

He was the son of the late Professor T. H. Core and was educated at Manchester Grammar School and the University of Manchester, where he had a very distinguished career. After holding a number of resident hospital posts and studying abroad, he returned to Manchester as a consulting physician and was on the honorary staff of several local hospitals, including the Manchester Royal Infirmary.

He soon became interested in Neurology and Psychological Medicine and was appointed Lecturer in Neurology. He contributed a number of papers on these subjects and also two books—"Functional Nerve Disorders" and "Examination of the Central Nervous System." During the war, whilst serving with the 33rd British General Hospital in Mesopotamia, his health broke down and he never fully recovered. In spite of impaired physical strength, he continued his clinical work and published some of his most important studies on functional nervous disorders, which became more and more his main interest. His work was characterised by a close attention to detail and a philosophic outlook. In later years, ill-health

caused him to lead a rather reserved and retired life, and he undoubtedly conserved all his energies for his medical work. Yet he was a popular member of many scientific societies and a stimulating conversationalist.

His death at an early age is a serious loss to the Manchester Medical School.

J. S. B. S.

PROCEEDINGS.

ORDINARY MEETING, October 3rd, 1933.

Mr. JOHN ALLAN (*President*) in the Chair.

The following papers were read in title :—

" ' Unshared ' Electrons and the Effects produced by *o-p*-Directive Substituents in Organic Molecules."

By G. N. BURKHARDT M.Sc., Ph.D., and M. G. EVANS, M.Sc.

" The Occurrence of the Genus *Platanus* in the Lough Neagh Clays and other Tertiary Deposits of the British Isles."

By T. JOHNSON, D.Sc., F.R.S.E.

These papers are printed in the MEMOIRS, Vol. 77, 1932-33.

Mr. JOHN ALLAN, F.C.S., gave his Presidential Address on **" Ancient Buddhist Remains in Central Java."**

A Hindu empire was in existence in Java from 557 B.C. to 477 B.C. In 244 B.C. Buddhist propaganda was initiated by the King of Behar, and although Brahmin doctrines were indefinitely attributed to the year A.D. 75, it is certain that later Buddhist invasions of priests, warriors, and craftsmen took place in the fifth and seventh centuries. To-day the country is essentially Mohammedan.

The Boro-Budur, which is the greatest and oldest of the hundreds of temples of the Madjaphit Plain, is purely Buddhistic. It was built of grey volcanic lava, without lime or mortar, being jointed by tenons, mortices, and dovetails. It consists of nine galleries, the greatest of which is over 530 feet long,

built round an earthen core; the six lower galleries being square with re-entrant angles, and the three upper being circular and surmounted with openwork dagobas containing statues of the Buddha. Bas reliefs cover the walls of the galleries. The whole is surmounted by a huge dagoba of 52 feet diameter, the total height of the structure from base to summit being about 150 feet.

At Kedri recent excavations disclosed temples with baths and fine carving. The Dyeing Plateau where many temples were built was subject to flooding and a tunnel which still exists was built to drain away the water. There are five great groups of temples left, some in complete ruin and others fairly well preserved.

ORDINARY MEETING, October 17th, 1933.

Mr. R. H. CLAYTON in the Chair.

Professor T. B. L. WEBSTER read a paper on

"The Greek Vases in the Manchester School of Art."

This paper is printed in the MEMOIRS.

ORDINARY MEETING, Tuesday, October 31st, 1933.

Mr. JOHN ALLAN (*President*) in the Chair.

Dr. W. H. TAYLOR read a paper on

"The Structure of Felspars and Zeolites."

A large number of silicate structures are based on frameworks of linked tetrahedral groups of oxygen atoms. Each tetrahedral group has at its centre a silicon or aluminium atom, and the remaining atoms (such as sodium or potassium) and molecular groups (such as water) occupy cavities within the tetrahedron framework.

The felspars furnish simple examples of this type of structure. The framework is essentially the same in all felspars; in the monoclinic potassium-barium felspars the atoms occupying cavities are large and so the framework is widely extended, but in the triclinic plagioclases the framework has collapsed around the smaller sodium and calcium atoms.

The zeolites are more complex than the felspars, but the structures are based on strong tetrahedron frameworks, which are penetrated by "channels" or "tunnels" of such a size as to permit the movement of water molecules and kations. The existence of the channels explains in a reasonable way the peculiar dehydration and base-exchange properties of zeolites.

GENERAL MEETING, Tuesday, November 14th, 1933.

Mr. JOHN ALLAN (*President*) in the Chair.

The following gentlemen were elected Ordinary Members of the Society :—

DAVID STEWART, University Lecturer in Anatomy, of the University, Manchester.

GEORGE FRANCIS CLAYTON, Student, of 1 Parkfield Road, Didsbury, Manchester.

ORDINARY MEETING, Tuesday, November 14th, 1933.

Dr. G. N. Burkhardt gave a summary of the work which has been done in connection with the carotenoid pigments.

A rapidly developing field of investigation centres on carotene, the pigment of the carrot, which also occurs in most green leaves. The general interest of this work was greatly increased when it was found (*a*) that carotene has a physiological action similar to that of vitamin A (growth promoting), (*b*) that when animals deficient in vitamin A are fed with carotene, the vitamin forms in the liver, and (*c*) that the carbon skeleton of the vitamin ($C_{20}H_{29}OH$) is half the symmetrical structure of carotene ($C_{40}H_{56}$) and that a wide range of natural colouring matters are also simply related to this pigment.

ORDINARY MEETING, November 28th, 1933.

Mr. JOHN ALLAN (*President*) in the Chair.

Professor D. R. HARTREE read a paper on

"A Practical Method for the Numerical Solution of Differential Equations."

This paper, which describes a highly practical method for the solution of intractable differential equations, is printed in full in the MEMOIRS AND PROCEEDINGS, Vol. 77, 1932-33.

ORDINARY MEETING, Tuesday, December 12th, 1933.

Mr. JOHN ALLAN (*President*) in the Chair.

Dr. J. M. NUTTAL read a paper on

"The Neutron and Positive Electron."

When α particles bombard many light elements, a very penetrating radiation is emitted. Since the properties of this radiation cannot be reconciled with those of a high energy quantum, Chadwick suggested that the radiation consists of neutrons or particles of unit mass and having no net charge. It is assumed that the α particle is captured by the bombarded nucleus, with the formation of a new nucleus and the ejection of a neutron. The neutron will penetrate matter very easily as it can only lose energy by direct collisions with other nuclei. The evidence shows that the mass of the neutron is about 1·006 and supports the view that it is a complex particle consisting of a close combination of a proton and an electron. This model, however, leads to theoretical difficulties. Although in general the collisions of neutrons with atomic nuclei are of the elastic type (giving recoil atoms), occasionally the neutron disintegrates the nucleus with which it collides. The main interest in the neutron lies in its importance as a new unit of nuclear structure. The positive electron, first posulated by Dirac from theoretical considerations was later observed experimentally by Anderson and Blackett. There is some evidence of the simultaneous creation of positive and negative electrons by the mutual interaction of a strong γ ray and the electric field of a nucleus.

"YOUNG PEOPLE'S MEETING," January 9th, 1934.

The Fourteenth "YOUNG PEOPLE'S MEETING" was held at 3.30 p.m., when the following short illustrated addresses were given :—

"Electric Discharges."

By Dr. H. LOWERY, M.Sc.

"Camels and all that."

By Miss C. M. LEGGE, M.A.

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GENERAL MEETING, Tuesday, January 16th, 1934.

Mr. JOHN ALLAN (*President*) in the Chair.

The following gentleman was elected an ordinary member of the Society:—

FRANK MOULTON SAXELBY, of 21 Broad Walk, Buxton.

ORDINARY MEETING, Tuesday, January 16th, 1934.

Mr. A. MCLEAN RANFT read a paper on

"High Voltage Generation."

Mr. Ranft surveyed the development of High Voltage Alternators in connection with electrical transmission and distribution.

He dealt with the development of Alternators generating at 36,000 volts, and referred to some features of the extensive research on this subject carried out by Messrs. C. A. Parsons & Co. Ltd., at Heaton Works, Newcastle-on-Tyne, under the direction of the late Sir Charles Parsons.

It was shown that a great advance has been made in the technique of alternator design to meet the conditions under which the National Grid Transmission System is operating, and that there are now in service and under construction seven High Voltage Turbo-Alternators of an aggregate capacity of 168,000 kW. embodying the invention of the Triple Concentric Conductor.

Mr. Ranft mentioned that it has been authoritatively stated, that where a system is operating at 33,000-36,000 volts, the High Voltage Alternator effects a substantial saving in capital expenditure and operating costs, due to the elimination of step-up transformers necessary with low voltage alternators.

As to the future of High Voltage Generation, there can now be no question. The concentric conductor principle enables a machine to be built with a very high factor of safety. Indeed, the margin of safety is so great, that the same construction would be perfectly adequate for an alternator to work at 50,000 volts, while by substituting quadruple for triple concentric conductors, and making other minor alterations, the working pressure could be raised with perfect safety to 66,000 volts, which is the second highest transmission pressure in general use in this country. Switching is already carried out in power stations at this pressure, and generation at the same voltage seems bound to follow.

The problems connected with Dielectric Loss and Insulation at High Voltage were reviewed and discussed. Lantern slides were shown illustrating the salient features of this far-reaching achievement in the field of Electrical Engineering.

ORDINARY MEETING, January 30th, 1934.

Mr. JOHN ALLAN (*President*) in the Chair.

Mr. C. E. STROMEYER, O.B.E., communicated a paper on

"Earth Movements—The building of mountain ranges and their influence on cyclic changes of climate."

By C. P. STROMEYER.

The Author dealt with three problems which have puzzled geologists and others :—

(1) If, as seems to be imagined, the numerous dykes in the earth's crust (cracks into which once molten lava has penetrated) have been caused by tension stresses their sides would be parallel. If they were caused by pressure from below and bending, then their sides would taper downwards to a point and lava could not have entered them. But the sides of actual dykes are wider apart low down, and may have met high above the present level at a point which marks the tormer thickness of the stratum at the time of the occurrence of the crack. There will have been a horizontal thrust normal to the line of the resulting crack. This will have crushed the rock at some distance beyond the crack and as all thrust fractures are inclined at angles of 45° to the direction of the thrust the one side of this sloping fracture will have glided up the other slope thereby causing the crust to bend and break with a fracture, which as required would be a close contact at the top and wide open at the bottom and lava would rise up in it. Congealed it would cement the two sides firmly together and if after a time the thrust was renewed new dykes, parallel to the first, would be formed.

(2) It seems to be admitted that the puckerings on the earth's surface, or mountains, are due to thrusts, and by means of a simple geometrical construction it can be shown that a very slight end movement of a flat arch will create a quite disproportionately large upheaval. The Author suggests that these trifling end movements are due to long continued depositions of sand and sediment on the floors of the oceans where they act like blankets, and allowing the original floors

to grow warmer at the rate of about 1° F. per 60 ft. depth, that being the average temperature gradient in the known crust. These deposits are the abrasions and denudations from the mountain sides and tops, and if they are deposited on either side of the mountain range, as is the case with regard to the Andes then, as can easily be shown, the rate at which these mountains rise can be greater than their abrasion. Gradually the underlying originally fluid granite will appear at the mountain tops. It will have been drawn up and not thrust up by subterranean powers, as seems to be believed, though no explanation can be given as to their mode of action. The cooling of the material of the mountain ranges should cause cracks to occur. These cracks would have parallel sides.

(3) There are numerous ranges of granitic intrusions, some of great antiquity for they are nearly covered by more recent stratified rocks. Their number indicated that the building up process has been repeated many times and as often interrupted. The Author suggests that these changes are intimately associated with the climatic changes known as recurring ice ages.

The ice sheet of the last one extended as far south as middle Europe and north of Florida, regions which now enjoy a mean yearly temperature of about 20° C. (68° F.). Such an increase of temperature can most readily be accounted for by what is known in the Alps as the Foehn winds, caused by moist air ascending on the one side of a mountain where its moisture is deposited as rain, and descending as dry, but very warm wind on the other side. Let it be assumed that a mountain range of 2,000 m. (6,000 ft.) height has been placed across the east or west winds of the several latitudes, similar to the Andes and Rockies. Selecting one latitude where the bottom or surface temperature of the air is 20° C. (68° F.), and assuming the average temperature gradient of 1° C. per per 100 m. height, then as this warm moist air passes over the 2,000 m. height its moisture of 1·7 grams per cub. m. is lost as rain down to 0·47 grams per cub. m. By means of this loss the temperature of the dried air will have been raised 26° C. (47° F.) which increase is maintained during the descent on the lee side of the mountains. Similar but not such large increases of temperature are experienced by higher layers of air with the two-fold result that the new temperature gradient of 1° C. per 100 m. is seriously exceeded and whirlwinds and mixings result and

that the average temperature rise of the Fœhn is only 20° C. (36° F.) which will therefore be felt as being 104° F. hot.

This continuous supply of heat to the atmosphere is continuously balanced by the earth's radiation loss, and steady conditions prevail. If this heat supply were to be reduced by a lowering of the mountain heights then the radiation loss would have to follow suit, which would only be possible by a reduction of temperature of the earth's surface. It would thus appear that there is a close relation between the heights of the mountains on the earth and its temperature. It must not, however, be overlooked that on account of the slowness of these changes, even in a geological sense, they do not necessarily coincide.

Dr. J. WILFRID JACKSON gave an illustrated lecture on

"Excavations in Caves at Ballintoy, Northern Ireland."

Dr. Jackson stated that last year he directed extensive excavations in two chalk-caves on the sea-coast at Ballintoy, Co. Antrim. The work was carried out by means of a grant from the Belfast Corporation for archæological research in Northern Ireland, and by the kind permission of the landowner, Mr. Francis M'Shane. During part of the time, Miss M. Gaffikin, of Belfast, Mrs. Anderson, of Downpatrick, and Professor J. K. Charlesworth, of Queen's University, Belfast, rendered valuable assistance. Four local workmen were employed to do the digging.

One of the caves is known locally as Park Cave and its floor was estimated to be about 15 feet above mean-tide level. The excavations revealed that Raised Beach material, consisting of clean shingle of hard chalk and flints, extended to the back of the cave. Some flints showing signs of human workmanship were found in this material. A few are like the typical cream-coloured patinated flakes of the "25 foot Raised Beach" at Larne, and in addition there is at least one typical *petit tranchet* implement.[1] Overlying the beach material was a dark occupation layer of earth and rounded boulders containing Early Iron Age pottery, shells of edible species, animal remains, and bone

[1] The Raised Beach implements are regarded as Campignian, and the *petit tranchet* is typical of the Campignian and Kitchen-midden cultures of the continent.

implements. Over this again was a deposit of blown sand and at the surface a layer of earth and matted seaweed.

The other cave was discovered by Dr. Jackson at the foot of a tall chalk cliff a little distance away. It was masked by fallen debris and by boulder-clay which had slipped down a nearby gully. The cave-arch is about 20 to 25 feet above mean-tide level, and the cave lies farther from the sea than Park Cave. From the finds made it was called Potters' Cave. Excavations outside the cave-mouth revealed several occupation layers of the Early Iron Age containing much pottery, animal and fish remains, shells of limpets, and other edible species, implements of bone and stag-antler, and some flint knives and flakes. The pottery shows some variety in style and paste, much of it consisting of fragments of base and rim of almost straight-sided vessels, the rims being flattened and occasionally ornamented by cuts, notches or thumbprints. The sides are mainly without ornament, but a few pieces show rough combing, scraping or finger-grooving. Some sherds have an applied band below the rim, and a few have a neatly drilled hole about 1½ inches below the top—the so-called soul-hole, or Seelenloch, of German archæologists, found in the sides of clay ossuaries from the Urnfield Culture of Hungary (end of the Middle Bronze Age). On the whole the pottery shows affinities with that of the Late Halstatt Period of England and elsewhere. Among the bone implements are piercers and needles, including a fine polished example, 2 inches long, with a perfectly formed eye (perhaps a fish-spine), and a small double-ended and ornamented comb.

The most remarkable and unique find at Potters' Cave is a roughly-fashioned female figurine in baked clay agreeing in paste with some of the sherds. This, the first discovery of its kind for Ireland, resembles a Mother Goddess : it is incomplete, being 4 inches high and 2¾ inches across the shoulders. The ears, eyes and mouth are indicated by holes made in the clay : there is also a round hole in the centre of the forehead. The arms are broken and the legs are missing. The breasts are well-formed, somewhat pendulous, and placed high up. Certain resemblances exist between the figure and the statue menhir at St. Martin de la Bellouse, Guernsey. Clay figurines of a goddess have been found in the Urnfield cultures of Hungary.

An interesting tanged flint point of the Bann type was found at a depth of about 6 feet from the surface. It differs in colour

and patination from the other flints found at this cave, and may be a derived specimen. It resembles some examples from Culbane, Bann Valley, figured by Dr. Jackson in 1909 (see *Mem. and Proc. Manch. Lit. and Phil. Soc.*, Vol. 53, Pt. II., plate II. top row). The age of the Bann flint culture is still under discussion: it may be Late Mesolithic; and later than that of the Larne culture.

Well below the Early Iron Age occupation of Potters' Cave some flint flakes were found in association with a charcoal layer, limpet shells and a few animal bones. The date of this early occupation is not yet clear. The Raised Beach deposits were not reached though excavations were made to a depth of over 10 feet.

ORDINARY MEETING, February 15th, 1934.

Mr. JOHN ALLAN (*President*) in the Chair.

Mr. D. C. HENRY, M.A., delivered an experimental lecture on

"Some Very Sensitive Chemical Tests."

At one time the spectroscope was pre-eminent in the detection of minute traces of certain chemical elements, but there now exist chemical tests which rival or even exceed the spectroscope in sensitivity. The spectroscopic method, as well as a number of chemical tests, were demonstrated by experiments, which included colour reactions sensitive to one part in several millions, test reactions projected from the stage of a microscope and a method of detecting the watering of milk. The experiments and explanations were of a non-technical nature, designed to be of interest to others besides chemists.

SPECIAL MEETING, February 27th, 1934.

Mr. JOHN ALLAN (*President*) in the Chair.

Professor E. A. MILNE, F.R.S., delivered the Joule Memorial Lecture on

"The Expanding Universe as a Thermodynamic System."

This lecture is printed in the MEMOIRS.

ORDINARY MEETING, March 13th, 1934.

Mr. JOHN ALLAN (*President*) in the Chair.

Mr. J. B. M. HERBERT, M.Sc., delivered a lecture on

" Heavy Waters."

Isotopes are defined as elements having the same atomic number but different atomic weights. Except in the case of the heavy hydrogen isotope (diplogen) the chemical properties of isotopes are identical.

" Heavy hydrogen " or " diplogen " (D) as it has been suggested that it be named, has an atomic weight—2·0135 as compared with normal hydrogen (H)—1·0077, and occurs in normal hydrogen to the extent of 1 in 30,000. It was discovered spectroscopically by Urey and Murphy in 1928. It has been prepared in a fairly pure condition by the electrolysis of water in which process the light isotope is preferentially evolved at the cathode. The residual liquid is therefore richer in " heavy water " (D_2O) than is the original liquid. This heavy water has a density 10 per cent. greater than normal water, boils at 101° C. and freezes at 3·8° C. A further interesting property is that it is lethal. A specimen containing 92 per cent. of D_2O kills tadpoles in less than one hour, flatworms in about two hours and protozoa in about two days. Seeds will not germinate in it. A specimen of water containing only 30 per cent. heavy water is not fatal to living organisms.

Diplogen is of great interest to the chemist because it is the one case in which the chemical reactions of isotopes are very different. This is the case for two reasons : (i) The ratio of the masses of the two isotopes is large (2 : 1), and (ii) the light isotope H is sufficiently light to resemble a wave rather than a particle when applying the new quantum mechanics, while the heavy isotope D behaves more like a particle than a wave. Comparison of the velocities with which the two forms react chemically provide the physical chemist with very useful data by which to check his theories.

The lethal action of heavy water seems to be due to the lessened velocity of reaction of the heavy isotope which upsets the equilibria of the living organism, and thus leads to its death.

Heavy Oxygen (atomic weight 18) is much more difficult to prepare in a pure form than is heavy hydrogen. So far the best specimens prepared have not contained more than 1 or 2 per cent. of the isotope.

Its importance to the chemist lies in the fact that mixing a little of it with ordinary oxygen is equivalent to tying a red label on to the oxygen molecules, allowing their wanderings in a chemical reaction to be followed.

ORDINARY MEETING, Tuesday, March 27th, 1934.

Mr. JOHN ALLAN (*President*) in the Chair.

Mr. R. A. OGG read the following paper :—

"The Mechanism of Ionogenic Reactions."

By R. A. OGG, Ph.D., and M. POLANYI, M.D., Ph.D.

This paper is printed in the MEMOIRS.

ANNUAL GENERAL MEETING, Tuesday, April 24th, 1934.

Mr. C. E. STROMEYER (*Vice-President*) in the Chair.

The following gentlemen were balloted for and declared duly elected ordinary members of the Society :—

FREDERICK HARRIS, of 9 Outwood Drive, Heald Green, and MAX WITTE, of Dunham Rise, Altrincham.

The Annual Report and Statement of Accounts were approved.

The existing Officers of the Society were re-elected unopposed. The following gentlemen were elected to be Members of Council :—

Dr. G. N. Burkhardt, Mr. J. D. Chorlton, Professor H. J. Fleure, Dr. J. W. Jackson, Mr. R. W. James, Mr. P. Guthlac Jones, Professor W. H. Lang, Mr. A. M. Ranft, and Mr. A. D. Ritchie.

A vote of thanks to the Hon. Auditors, Miss G. G. Clegg and Mr. Howard Cheetham, was passed, and they were re-elected for the coming session.

ORDINARY MEETING, Tuesday, April 24th, 1934.

Mr. HENRY made a short communication dealing with a paper by M. POLANYI and J. HORIUTI on

"The Ionisation of Hydrogen on a Platinum Catalyst."

This paper is printed in the MEMOIRS.

Mr. ERNEST F. LANG gave a demonstration of lantern slides in natural-colour photography of "The Oberammergau Passion Play."

GENERAL MEETING, Tuesday, May 8th, 1934.

Dr. E. C. SCOTT DICKSON in the Chair.

The following gentlemen were elected Ordinary Members of the Society :—

PHILIP SIDNEY HILLARD HENRY, Research Physicist of 90 Burton Road, Withington.

MICHAEL POLANYI, Professor of Chemistry, of Kenmore, Didsbury Park, Didsbury.

ORDINARY MEETING, Tuesday, May 8th, 1934.

Dr. J. W. JACKSON exhibited some flint flakes dredged from the River Bann, south of Coleraine, Northern Ireland. These were of a striking magenta colour due to the presence of a rare encrusting freshwater alga, *Hildenbrantia rivularis* (Lieb.) J. Ag.

Professor DAVID KATZ delivered the following lecture :—

"The Tongue as a Primitive Sense-Organ."

This lecture is printed in the MEMOIRS.

CHEMICAL SECTION.

ORDINARY MEETING, Friday, October 27th, 1933.

Mr. LEIGH PEARSON, M.Sc., F.I.C., read a paper on

" Flour Milling and Grain Conveying."

ORDINARY MEETING, Friday, November 24th, 1933.

Dr. J. ROBINSON, M.D., Ch.B., read a paper on

" Dope."

JOINT MEETING WITH THE MANCHESTER SECTION OF THE SOCIETY OF DYERS AND COLOURISTS, Friday, December 15th, 1933.

Mr. E. CHIPPINDALE read a paper on

" The Acetylation of Cellulose and its Application in the Electrical and Textile Industries."

ORDINARY MEETING, Friday, January 26th, 1934.

Mr. J. GALLOWAY WALTHEW, M.I.M.E., and Mr. H. T. WILLIAMS, B.Sc., M.I.Min.E., introduced a discussion on

" Coal *v.* Oil."

ORDINARY MEETING, February 23rd, 1934.

Mr. VICTOR H. FINNEY introduced a discussion on

" The Economics of Industry."

ANNUAL GENERAL MEETING, March 23rd, 1934.

The following members were elected Officers and Members of the Committee of the Section for the year 1934-35 :—

Chairman. L. M. Angus-Butterworth, F.R.G.S., F.S.A.

Vice-Chairman. A. Gill, B.Sc., A.I.C.

Secretary. David M. Paul, B.Sc., A.I.C.

Committee. G. N. Burkhardt, Ph.D., F.I.C. ; H. Cheetham, Fel.C.I.P.A. ; H. Hayhurst ; R. Humphreys, A.I.C. ; P. Guthlac Jones ; E. N. Marchant ; T. O. Morgan ; H. Stevenson, F.I.C.

ORDINARY MEETING, March 23rd, 1934.

Mr. B. J. TAMS, B.Sc., M.Sc.Tech., A.M.I.M.E., introduced a discussion on

" Modern Oil Engines."

ANNUAL REPORT OF THE COUNCIL, APRIL, 1934.

Membership.

During the session three new members have been elected, and the Society has to record the death of three ordinary members (Dr. Herbert Carrington, Dr. Donald Core, and His Honour Judge Bradley). To March 31st, 1934, there are 193 ordinary members, including six life members. There have been six resignations.

Student Associates.

During the session the Council has elected one student associate member.

Meetings.

During the year April 1st, 1933, to March 31st, 1934, fourteen papers have been read before the Society, and at the meeting held on November 14th, short communications were made by members.

A joint meeting with the other Manchester Chemical Societies was held at the College of Technology on November 3rd, when Sir Robert Robertson, K.B.E., F.R.S., lectured on "Research in the Infra Red."

Six meetings and a Soirée have been held by the Chemical Section, one being a combined meeting with the Manchester Section of the Society of Dyers and Colourists, when a paper on "The Acetylation of Cellulose and its Application in the Electrical and Textile Industries" was read by Mr. E. Chippindale.

Society's Accounts.

An audited report of the Society's cash account is attached to this report, together with a statement of assets and liabilities.

Society's Library.

The total number of volumes catalogued is approximately 46,907: the additions to the library amounting to 752 volumes,

749 serials, and 3 separate works. Gifts have been received from Mr. Stromeyer, Dr. Ashworth, and others.

Volume 77 of the Memoirs and Proceedings has been published during the year, and a new exchange has been arranged with L'Ecole Polytechnique " Roi Carol II.," Bucarest.

Gifts.

The Society has accepted the gift of a piece of glass apparatus, believed to have belonged to John Dalton, from Major Peer Groves.

Chemical Section.

At the Annual General Meeting of the Section the following officers were elected :—

Chairman : Mr. L. M. Angus-Butterworth ; *Vice-Chairman :* Mr. A. Gill ; *Secretary :* Mr. D. M. Paul.

At March 31st, the Section had a membership of 77.

The following subjects have been discussed at meetings during the year :—

" Flour Milling and Grain Conveying " (Mr. Leigh Pearson) ; " Dope," (Dr. J. Robinson) ; " Coal *v.* Oil " (Mr. J. Galloway Walthew, and Mr. H. T. Williams) ; " The Economics of Industry " (Mr. Victor H. Finney) ; " Modern Oil Engines " (Mr. B. J. Tams).

Visiting Societies.

The following Societies have held meetings in the Society's rooms : The Manchester Astronomical Society ; The Institution of Civil Engineers (Manchester Association) ; The Manchester Microscopical Society ; The Manchester Statistical Society ; The Society of Dyers and Colourists (Manchester Section) ; The Institution of Locomotive Engineers (Manchester Centre) ; The Ancient Monuments Society, and the Biological Association.

Committees.

The Council have appointed the following committees :—

House and Finance.

Dr. Carpenter and Mr. Guthlac Jones.

Wilde Endowment.

Dr. Carpenter and Dr. Pickard.

Publications.

Mr. James and Dr. Carpenter. (Mr. Ritchie and Professor Fleure were co-opted by the President to give advice to the Council.)

Library and Apparatus.

Dr. Ashworth, Professor Bragg and Dr. Pickard.

New Premises.

Mr. James, Dr. Ashworth and Mr. Chorlton.

The President, Secretaries, Treasurer, and Librarians, are *ex-officio* members of these committees.

Chemical Section.

Mr. H. Cheetham, Mr. M. F. S. Choate, Mr. Hannay, Mr. Hayhurst, Mr. R. Humphries, Mr. Marchant, Mr. Morgan, Dr. Soutar, and Mr. Stevenson.

MANCHESTER LITERARY

Dr. *R. H. Clayton, Treasurer, in Account with the*

GENERAL

		£	s.	d.	£	s.	d.
To Balance in Treasurer's Hands, 1st April, 1933					15	19	3½
To Members' Subscriptions :—							
Half Rate	1932-33, 3 at £1 1s. od.	3	3	0			
„	1933-34, 13 „ „	13	13	0			
Full Rate	1931-32, 2 „ £2 2s. od.	4	4	0			
„	1932-33, 14 „ „	29	8	0			
„	1933-34, 146 „ „	306	12	0			
Life Composition Fee		5	5	0			
Part Life Composition Fee		1	5	0			
Student Associate Fee		0	5	0			
					363	15	0
To Sale of Publications					20	0	8
To Dividends :—							
Natural History Fund		45	18	8			
Joule Memorial Fund		11	14	1			
General Fund		2	12	6			
					60	5	3
To Transferred from Wilde Account					601	5	0
To Donation to the Society—Dr. C. S. Myers .					5	5	0
To Donations from Visiting Societies towards Expenses of Meetings :—							
Manchester Astronomical Society		6	0	0			
„ Inst. Civil Engineers		15	0	0			
„ Inst. of Locomotive Engineers .		12	12	0			
Ancient Monuments		1	5	0			
Society of Dyers and Colourists		5	0	0			
Manchester Microscopical Society		20	0	0			
					59	17	0
To Refund on Insurance Premiums . . .					2	13	7
To Proceeds of Telephone Box					0	3	6
To Payment towards cost of Collotype Plate .					5	0	0
To Overdraft at Bank, April 1st, 1934 . . .					416	14	1
					£1550	18	4½

AND PHILOSOPHICAL SOCIETY.

Society, from 1st April, 1933, to 31st March, 1934. **Cr.**

FUND.

	£	s.	d.	£	s.	d.
By Overdraft at Bank, 1st April, 1933				773	18	8
By Charges on Property :—						
Chief Rent	9	13	10			
Fire Insurance	15	0	0			
Income Tax	3	4	6			
				27	18	4
By House Expenditure :—						
Coal, Gas, etc.	59	1	9½			
Tea, etc., at Meetings	13	6	3			
Cleaning, etc.	9	10	11½			
Repairs and Replacements	3	17	5½			
				85	16	5½
By Administrative Charges :—						
Caretaker and Housekeeper	126	14	4			
Insurance against Liability	0	18	1			
Postages, Carriage, etc.	30	17	11			
Stationery	13	5	4			
Bank Charges	2	8	4			
Share of Expenses of Joint Meeting	0	7	3½			
National Health Insurance Stamps	17	15	5			
Young People's Meeting	8	11	9			
Miscellaneous Expenses	13	4	8			
				214	3	1½
By Printing, "Memoirs," Circulars, etc.				254	9	5
By Periodicals (except those charged to Natural History Fund)				75	4	9
By Periodicals—Natural History Fund				15	16	3
By Post Office Telephone				11	15	8
By Bookbinding				12	14	0
By Subscriptions :—						
North-West Naturalists Union	0	14	0			
T. A. Coward Memorial	2	2	0			
Royal Entomological Society	5	5	0			
Lancashire and Cheshire Fauna Committee	1	1	0			
Chemical Society Joint Advisory Committee	5	5	0			
				14	7	0
By Joule Memorial Lecture				21	0	0
By Transferred to Wilde Fund				18	15	0
By Cash in Treasurer's Hands, 1st April, 1934				24	19	8½
				£1550	18	4½

WILDE ENDOWMENT FUND, 1933-34.

Dr.	£	s.	d.	Cr.				£	s.	d.
To Balance at Bank, April 1st, 1933	548	2	8	By Assistant Secretary's Salary				168	15	0
To Dividend, Gas Light and Coke Company's Ordinary Stock (£7500)	315	0	0	By Repairs and Replacements				11	3	6
To Refunded Income Tax 1932-33	124	14	9	By Transferred to General Fund				500	0	0
To Part Assistant Secretary's salary refunded from General Fund	18	15	0	By Transferred to General Fund—						
To Bank Interest	1	8	1	13 Subscriptions at £1 1s. 0d.	£13	13	0			
				Entrance Fees	12	12	0			
				In lieu of Rent	50	0	0			
				Bookbinding	25	0	0			
								101	5	0
				By Balance at Bank, April 1st, 1934				226	17	0
	£1008	0	6					£1008	0	6

BUILDING FUND, 1933-34.

	£	s.	d.		£	s.	d.
To Balance at Bank, April 1st, 1933	474	18	9	By Balance at Bank, April 1st, 1934	563	3	5
To Rents	59	4	8				
To Interest on £400 Funding Loan 4 per cent. Stock	28	0	0				
To Bank Interest	1	0	0				
	£563	3	5		£563	3	5

JOULE MEMORIAL FUND, 1933-34. (Included in the General Account, above.)

	£	s.	d.		£	s.	d.
To Dividend on £100 East India Railway Company's 4½ per cent. Annuity Class A Stock	3	16	7	By Balance Transferred to the General Fund	11	14	1
To Interest on £250 3½ per cent. War Loan Stock	7	17	6				
	£11	14	1		£11	14	1

NATURAL HISTORY FUND, 1933-34. (Included in the General Account, above.)

Dr.	£	s.	d.	Cr.	£	s.	d.
To Dividend on £1225 Great Western Railway Company's Stock	45	18	8	By Natural History Periodicals	15	6	3
				By Subscription—North-Western Naturalists' Union	0	14	0
				By Balance Transferred to General Fund	29	18	5
	£45	18	8		£45	18	8

STATEMENT RELATING TO THE SOCIETY'S PROPERTY AS ON 31st MARCH, 1934.

LIABILITIES.	£	s.	d.	ASSETS.	£	s.	d.
Printing :—				Arrears of Subscriptions, 1933-34 (estimated to produce)	37	16	0
In the Press, Vol. 78 (estimated)	150	0	0	Arrears of Subscriptions, earlier (estimated to produce)	52	10	0
Binding (estimated)	75	0	0	Rents to Lady Day, 1934	15	10	0
Overdraft at Bank (General Fund)	416	14	1	Expenses of Meetings	33	11	0
				Cash Balance :—			
				In Bank, Building Fund	563	3	5
				„ Wilde Endowment Fund	226	17	0
					£929	17	5
	£641	14	1				
				Investments :—			
				£7500 Gas Light and Coke Company's Ordinary Stock (W.E.F.)			
				£1225 Great Western Railway Company's 5 per cent. Consolidated Preference Stock (Nat. Hist. F.)			
				£100 East India Railway Company's 4½ per cent. Annuity Class A (J.M.F.)			
				£250 3½ per cent. War Loan Stock, 1929-47 (J.M.F.)			
				£50 „ „ „ „ (W.E.F.)			
				£75 „ „ „ „ (Gen. Fund)			
				£700 4 per cent. Funding Loan (Building Fund)			
There are 6 Life Composition Fees.				Society's Premises, Furniture, Library, Collections, Stock of Unsold Publications, and New Premises, 21 and 21A Back George Street.			

NOTE.—The Treasurer's Accounts of the Session 1933-34 have been endorsed as follows:—

April, 12th, 1934. Audited and found correct.

We have seen at this date, the Bankers' certificate that they hold £375 of 3½ per cent. War Loan Bonds:—2 Bonds for £100 each, Nos. 71827 and 366270; 2 Bonds for £50 each, Nos. 131,577 and 31,358; 1 Bond for £50, and a Bond for £25, 3½ per cent. War Loan, 1929/47 Inscribed Stock; and the Certificates of the following Stocks:—£1225 Great Western Railway Company 5 per cent. Consolidated Preference Stock, Nos. 12,293, 12,294, and 12,323; £7500 Gas Light and Coke Company Ordinary Stock (No. 8/1960); £100 East India Railway Company £4 10s. per cent. Annuity Class A Stock (No. 25,656); £700 4 per cent. Funding Stock, 1960-1990, Nos. 34,185 and 23/3454; and the deeds of the Natural History Fund, of the Wilde Endowment Fund, those conveying land on which the Society's premises stand, and the Declarations of Trust.

Leases and Conveyances dated as follows:—
September 22nd, 1797.
September 23rd, 1797.
December 25th, 1799.
December 25th, 1799.
December 22nd 1820.
December 23rd, 1820.

Declarations of Trust:—
June 24th, 1801.
December 23rd, 1820.
January 8th, 1878.

Appointment of New Trustees:—
April 30th, 1851.

Conveyance relating to the property, 21 Back George Street, Manchester, dated 7th December, 1920.

We have also seen the Dalton and other Medals of the Society. We have verified the balances of the various accounts with the banker's pass books.

(*Signed*) GLADYS G. CLEGG,
HOWARD CHEETHAM.

LIST OF SOCIETIES AND INSTITUTIONS.

TO WHICH THE *Memoirs and Proceedings* ARE SENT.

Societies and Institutions present their publications to the Society's Library with the exception of those marked with a dagger (†).

Aberystwyth. †National Library of Wales.
Abo. Akademie Bibliotek.
Adelaide. Royal Society of Australia. South Australian Museum.
Amsterdam. Koninklijke Akademie van Wetenschappen. Société Mathématique.
Auckland. The Auckland Institute and Museum.
Augsburg. Der naturwissenschaftlicher Verein für Schwaben.

Baltimore. Johns Hopkins University.
Bamberg. Naturforschende Gesellschaft.
Bangalore (Madras). Indian Institute of Science.
Basle. Naturforschende Gesellschaft. Helvetica Chimica Acta.
Batavia. Koninklijke Natuurkundige Vereeniging in Nederlandsch-Indië. Bataviaasch Genootschap van Kunsten en Wetenschappen.
Bath. Bath and West and South Counties Society.
Belfast. Naturalists' Field Club.
Bergen. Geofysisk Institutt.
Berkeley. University of California.
Berlin. Preussische Akademie der Wissenschaften.
Berne. Schweizerische Naturforschende Gesellschaft.
Besançon. Société d'émulation de Doubs.
Birmingham. Natural History and Philosophical Society.
Bloemfontein. National Museum.
Bologna. Reale Accademia delle Scienze dell'Istituto.
Bombay. Branch of the Royal Asiatic Society of Bengal.
Bonn. Naturhistorischer Verein der preussischen Rheinlande und Westfalens.
Bordeaux. Société des Sciences physiques et naturelles.
Boston. American Academy of Arts and Sciences. Society of Natural History.
Boulder. University of Colorado.
Bremen. Naturwissenschaftlichen Verein.

Brisbane. Queensland Museum. Royal Society of Queensland. Royal Geographical Society of Australia, Queensland Branch.
Bristol. Naturalists' Society.
Brno. Faculty of Science, Masaryk University.
Brooklyn (N. Y.). Institute of Arts and Sciences.
Brussels. Académie Royale de Belgique. Musée Royal d'Histoire Naturelle de Belgique.
Buenos Aires. Sociedad Cientifica Argentina.
Buffalo. Society of Natural Sciences.

Caen. Académie nationale des Sciences, Arts et Belles-Lettres. †Société Linnéenne de Normandie.
Calcutta. Department of Agriculture in India, Agricultural Research Institute (Pusa). Geological Survey of India. Indian Association for the Cultivation of Science. Meteorological Department of India (Poona). Royal Asiatic Society of Bengal.
Cambridge. Philosophical Society. †University Library.
Cambridge (Mass.) Harvard College. †Massachusetts Institute of Technology Library.
Cape Town. Royal Society of South Africa. South African Museum.
Cardiff. Naturalists' Society.
Catania. Accademia Gioenia di Scienze naturali.
Chambéry. Académie des Sciences, Belles-Lettres et Arts de Savoie.
Chapel Hill. Elisha Mitchell Scientific Society.
Charlottenburg. Physikalisches-Technischen Reichsanstalt.
Cherbourg. Société nationale des Sciences naturelles.
Chicago. Astrophysical Journal. Field Museum of Natural History.
Cincinnati. Lloyd Library and Museum. †American Association for the Advancement of Science. Society of Natural History.
Clermont-Ferrand. La Société des amis de l'Université de Clermont.
Colorado Springs. Colorado College Coburn Library.
Columbia. University of Missouri.
Columbus. Ohio State University.
Copenhagen. Kongeligt Danske Videnskabernes Selskab. Kongeligt Nordisk Oldskrift-Selskab. Naturhistorisk Förening.
Cracow. Société Polonaise Mathématique.
Cullercoats. See Newcastle-upon-Tyne.

Danzig. Naturforschende Gesellschaft. Westpreussischer Botanisch-Zoologischer Verein.
Davenport. Academy of Natural Sciences.
Delft. Technische Hoogeschool.
Des Moines. Iowa Geological Survey.
Dijon. Académie des Sciences, Arts et Belles-Lettres
Dorpat. Naturforschende Gesellschaft.
Douai. Société d'Agriculture, Sciences et Arts du Départment du Nord.
Draguignan. Société d'études Scientifiques et Archéologiques.
Dublin. †National Library of Ireland. Royal Dublin Society. Royal Irish Academy. †Trinity College Library.
Dunkerque. Société Dunkerquoise pour l'encouragement des Sciences.
Durban. †Corporation Museum.

Elberfeld. Naturwissenschaftlicher Verein.
Épinal. Société d'émulation des départmentes des Vosges.
Edinburgh. Botanical Society. Geological Society. Mathematical Society. †National Library of Scotland. Royal Botanic Gardens. Royal Observatory. Royal Physical Society. Royal Society. Royal Scottish Society of Arts. †Scottish Meteorological Society.
Erlangen. Physikalisch-medizinische Societät.
Evreux. Société libre d'Agriculture, Sciences, Arts et Belles-Lettres de l'Eure.

Falmouth. Royal Cornwall Polytechnic Society.
Florence (Firenze). Biblioteca Nazionale Centrale.
Frankfurt-am-Main. Physikalischer Verein. Senckenbergische Naturforschende Gesellschaft.
Freiburg i. Br. Naturforschende Gesellschaft.

Geneva. Institute national Génévois. Société de Physique et d'Histoire Naturelle. See also Basle.
Genova. Museo Civico di Storia Naturale.
Giessen. Oberhessische Gesellschaft für Natur-und Heilkunde.
Glasgow. Geological Society. Natural History and Microscopical Society. Royal Philosophical Society. †University Library.
Görlitz. Naturforschende Gesellschaft.
Göteborg. Göteborgs Stadtsbibliotech (Högskole).
Göttingen. Gesellschaft der Wissenschaften.

Grahamstown. Albany Museum.
Granville. Denison University.
Gratz. Verein des Aertze in Steiermark.
Greenwich. Royal Observatory.

Haarlem. Hollandsche Maatschappig der Wetenschappen. Musée Teyler. Nederlandsche Maatschappig ter bevordering van Nijverheid.
Halifax, N.S. Nova Scotian Institute of Science.
Halle. Kaiserliche Akademie der Naturforscher. Naturforschende Gesellschaft und Naturwissenschaftlicher Verein.
Hamburg. Naturwissenschaftlicher Verein.
Hanley. See Stoke-on-Trent.
Hannover. Naturhistorische Gesellschaft.
Hartford (Conn.). Connecticut State Library (Geological and Natural History Survey).
Heerlen. Geologisch Bureau van het Nederlandsch Mijngebied.
Heidelberg. Bädische Sternwarte. Naturhistorisch-medizinischer Verein.
Helsingfors. Finska Vetenskaps Societeten. Societas pro Fauna et Flora Fennica.
Hermannstadt. Siebenbürgischer Verein für Naturwissenschaften.
Hobart. Royal Society of Tasmania.
Hong Kong. Royal Observatory.
Hull. †Scientific and Field Naturalists' Club. †Yorkshire Naturalists' Union.

Indianapolis. Department of Geology and Natural Resources of Indiana.
Iowa City. Iowa State University.
Ithaca. Cornell University. Agricultural Experimental Station.

Johannesburg. South African Association for the Advancement of Science.

Kazan. Imperial University. Society of Archæology.
Kiel. Kommission zur wissenschaftlicher Untersuchung der deutschen Meere in Kiel. Naturwissenschaftlicher Verein für Schleswig-Holstein.
Kiev. Society of Naturalists.
Kodaikanal. See Madras.
Königsberg i. Pr. Königliche Universitäts-Sternwarte. Königliche Physikalisch-ökonomisch Gesellschaft.
Kyoto. College of Science and Engineering, Imperial University.

La Plata. Direccion General de Estadistica de la Prov. Buenos Aires. Universidad Nacional, Facultad de Ciencias Fisico-Matematicas.
Lausanne. Société Vaudois des Sciences Naturelles.
Lawrence. Kansas University.
Leeds. Philosophical and Literary Society. Yorkshire Geological Society. Leeds Geological Association.
Leeuwarden. Friesch Genootschap, van Geschied-, Oudheid -en Taalkunde.
Leicester. Literary and Philosophical Society.
Leiden. Maatschappig der Nederlandsch Letterkunde. Rijks Geologisch—Mineralogisch Museum. Rijks Herbarium.
Leipzig. Naturforschende Gesellschaft. Fürstliche Jablonowskische Gesellschaft. Sächsische Gesellschaft der Wissenschaften.
Le Mans. Société d'Agriculture, Sciences et Arts de la Sarthe.
Lemberg. Société Scientifique de Chevtchenko.
Leningrad. Academy of Sciences of the Union of Socialist Soviet Republics.
Liége. Société Géologique de Belgique. Société Royal des Sciences.
Lille. Société des Sciences de l'Agriculture et des Arts. L'Université.
Lima, Peru. Cuerpo de Inginieros de Minas del Peru.
Lincoln, U.S.A. University of Nebraska.
Liverpool. Biological Society. Engineering Society. Geological Society. Literary and Philosophical Society.
London. British Association. British Museum (Natural History). British Museum (Library of Pure and Applied Science). Chemical Society. Faraday Society. Geological Society. Institution of Civil Engineers. Institution of Electrical Engineers. Institution of Mechanical Engineers. Linnean Society. Mathematical Society. Meteorological Office. National Central Library. Patent Office. Physical Society. Quekett Microscopical Society. Royal Society. Royal Astronomical Society. Royal Geographical Society. Royal Horticultural Society. Royal Institution of Great Britain. Royal Meteorological Society. Royal Society of Arts. † Subject Index to Periodicals. Zoological Society.
Lucca. Reale Accademia Lucchese di Scienze, Lettere, ed Arti.
Lund. Universitet.
Luxembourg. Institute Grand Ducal de Luxembourg.
Lwow. See Lemberg.
Lyon. Académie des Sciences. L'Université.

Madison. Wisconsin Academy of Sciences, Arts and Letters. Wisconsin Geological and Natural History Survey.

Madras. Observatory (Kodaikanal).

Madrid. Real Academia de Ciencias. Real Sociedad Matemática Española.

Manchester. Association of Engineers. †Athenæum. †Chetham's Library. †Christie Library. Conchological Society. Geographical Society. Geological Association. Microscopical Society. †Municipal College of Technology. †Reference Library. Shirley Institute. Statistical Society. Textile Institute.

Manila. Bureau of Science. Ethnological Survey.

Marburg. Gesellschaft zur Beförderung der gesammten Naturwissenschaften.

Marseille. Faculté des Sciences de l'Université.

Melbourne. Royal Society of Victoria.

Metz. Académie de Metz.

Mexico. Instituto Geológico. Sociedad Cientifico "Antonio Alzate."

Middleburg. Zeeuwsch Genootschap der Wetenschappen.

Milan. Reale Istituto Lombardo di Scienze e Lettere. Reale Osservatorio di Brera in Milano (Merati, Como.). Società Italiana di Scienze Naturali, e Museo Civico.

Minneapolis. University of Minnesota. †Academy of Natural Sciences.

Missoula. University of Montana.

Modena. Regia Accademia di Scienze, Lettere ed Arti.

Monte Video. Museo de Historia Natural.

Montpellier. Académie des Sciences et Lettres.

Montreal. Royal Society of Canada.

Munich. Bayerische Akademie der Wissenschaften.

Nancy. Société des Sciences de Nancy.

Naples. Accademia delle Scienze fisiche e matematiche. Accademia di Archeologia, Lettere e Belle Arti. Società Reale di Scienze.

Neuchâtel. Société neuchâteloise des Sciences naturelles.

Newcastle-upon-Tyne. Dove Marine Laboratories, Cullercoats. †Literary and Philosophical Society. Natural History Society of Northumberland, Durham, and Newcastle-upon-Tyne. University of Durham Philosophical Society.

New Haven (Conn.). Connecticut Academy of Arts and Sciences. Bingham Oceanographic Collection.

New York. Academy of Sciences. American Chemical Society. American Mathematical Society. American Museum of Natural History. Meteorological Observatory (Central Park). Vanderbilt Marine Museum.

Nîmes. Académie de Nîmes.

Norman. Oklahoma Academy of Science.

Norwich. Norfolk and Norwich Naturalists' Society.

Offenbach. Der Offenbacher Verein für Naturkunde.

Oslo. Norske Videnskaps Akademie. Norsk Meteorologisk Institut. Observatorium. Bibliothèque de l'Université Royale de Norvège.

Ottawa. Geological Survey of Canada.

Oxford. †Bodleian Library. Radcliffe Observatory. Radcliffe Library.

Palermo. Reale Accademia di Scienze, Lettere, e Belle Arti.

Paris. Académie des Sciences. École nationale supérieur des Mines. École polytechnique. Muséum d'Histoire naturelle.

Peiping. Geological Society of China.

Philadelphia. Academy of Natural Sciences. American Philosophical Society. Franklin Institute. †Philadelphia Commercial Museum. Wagner Free Institute of Science.

Pietermaritzburg. †Government Geologist, Surveyor General's Office. Natal Government Museum.

Plymouth. Plymouth Institution and Devon and Cornwall Natural History Society.

Portici. Laboratorio di Zoologia generale e agraria, R. Scuola sup. di Agricoltura.

Porto. Academica Polytechnica.

Prague. Königliche Böhmische Gesellschaft der Wissenschaft.

Puget Sound. See Seattle.

Pusa. See Calcutta.

Rheims. Académie nationale.

Riga. Naturforscher Verein.

Rochelle. Société des Sciences naturelles de la Charente inférieure.

Rochdale. Literary and Scientific Society.

Rochester, N.Y. Academy of Science.

Rock Island. Augustana College Library.

Rome. Institut International d'Agriculture. Reale Accademia dei Lincei. Società Italiana per il progresso delle Scienze. Vatican Observatory (Specola Vaticana).

Rostock. Verein der Freunde der Naturgeschichte in Mecklenburg.
Rouen. Académie des Sciences.

Sacramento. See Berkeley.
St. Louis. Missouri Botanical Garden. †Academy of Science. The Washington University.
St. Paul. See Minneapolis.
Salford. †Royal Museum and Library.
San Diego. Society of Natural History.
San Francisco. California Academy of Sciences.
Santiago. Deutscher Wissenschaftlicher Verein.
Sassari. Regia Università Istituto Fisiologico.
Seattle. University of Washington. Puget Sound Marine Biological Station.
Sendai. Tohoku Imperial University.
Sheffield. Midland Institute of Mining, Civil and Mechanical Engineers. Safety in Mines Research Board Laboratories.
Simla. See Calcutta.
Southport. Fernley Observatory.
Stockholm. Entomologiska Föreningen. Kongeliga Svenska Vetenskaps-Akademi. Royal Library. Sveriges Geologiska Undersökning.
Stoke-upon-Trent. North Staffordshire Field Club.
Stratford. The Essex Field Club.
Swansea. Scientific and Field Naturalists' Society.
Sydney. Australian Association for Science. Australian Museum. Linnean Society of New South Wales. Royal Society of New South Wales.

Tachkent. L'Université de l'Asie Centrale.
Taihoku. Imperial University.
Tartus. See Dorpat.
Teddington. National Physical Laboratory.
Tiflis. Geophysikalisches Observatorium Georgiens.
Tokyo. Faculty of Science, Imperial University of Tokyo. Imperial Academy. Institute of Electrical Engineers of Japan. National Research Council of Japan. Physico-Mathematical Society of Japan.
Torino. Società Meteorologica Italiana.
Toronto. Canadian Institute. University Library.
Toulouse. Académie des Sciences, Inscriptions, et Belles-Lettres.

Trondhjem. Kongelige Norske Videnskabers Selskab Museet.
Troyes. Société Académique d'Agriculture de l'Aube.
Tufts. Tufts College.
Turin. See Torino.

Uccle. L'Observatoire royal et l'Institut royal Météorologique de Belgique.
Upsala. Kongliga Universitet. Kongliga Vetenskaps-Societeten.
Urbana. Illinois State Geological Survey. Illinois State Laboratory of Natural History. University of Illinois.
Utrecht. Koninklijk Nederlandsch Meteorologisch Instituut. Provincial Utrechtsch Genootschap van Kunsten en Wetenschappen.

Venice. Reale Istituto Veneto di Scienze, Lettere, ed Arti.
Victoria, B.C. Dominion Astrophysical Observatory.
Vienna. Kaiserliche Akademie der Wissenschaften. Kaiserlich-Königliche Universitäts-Sternwarte. Kaiserlich-Königliches Naturhistorisches Hofmuseum. Kaiserlich-Königliche Zoologisch-Botanische Gesellschaft. Oesterreichische Gesellschaft für Meteorologie.

Washington University. See St. Louis, Mo.
Washington, University of. See Seattle.
Washington, D.C. Bureau of Standards, Dept. of Commerce and Labor. Carnegie Institute. National Academy of Sciences of the U.S.A. Smithsonian Institution. Smithsonian Institution, Bureau of Ethnology. Smithsonian Institution, United States National Museum. U.S. Coast and Geodetic Survey. U.S. Department of Agriculture. U.S. Geological Survey. U.S. Naval Observatory. †U.S. Patent Office.
Wellington, N.Z. New Zealand Institute.
Wiesbaden. Nassauischer Verein für Naturkunde.
Wurzburg. Physikalisch-medizinische Gesellschaft.

York. Yorkshire Philosophical Society.

Zurich. Naturforschende Gesellschaft. Schweizerische Meteorologische Central-Anstalt.

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THE WILDE LECTURES.

1897. (July 2.) "On the Nature of the Röntgen Rays." By Sir G. G. STOKES, Bart., F.R.S.

1898. (Mar. 29.) "On the Physical Basis of Psychical Events." By Sir MICHAEL FOSTER, K.C.B., F.R.S.

1899. (Mar. 28.) "The newly discovered Elements; and their relation to the Kinetic Theory of Gases." By Professor WILLIAM RAMSAY, F.R.S.

1900. (Feb. 13.) "The Mechanical Principles of Flight." By the Rt. HON. LORD RAYLEIGH, F.R.S.

1901. (April 22.) "Sur la Flore du Corps Humain." By Dr. ELIE METCHNIKOFF, For. Mem.R.S.

1902. (Feb. 25.) "On the Evolution of the Mental Faculties in relation to some Fundamental Principles of Motion." By Dr. HENRY WILDE, F.R.S.

1903. (May 19.) "The Atomic Theory." By Professor F. W. CLARKE, D.Sc.

1904. (Feb. 23.) "The Evolution of Matter as revealed by the Radio-active Elements." By FREDERICK SODDY, M.A.

1905. (Feb. 28.) "The Early History of Seed-bearing Plants, as recorded in the Carboniferous Flora." Dr. D. H. SCOTT, F.R.S.

1906. (March 20.) "Total Solar Eclipses." By Professor H. H. TURNER, D.Sc., F.R.S.

1907. (Feb. 18.) "The Structure of Metals." By Dr. J. A. EWING, F.R.S., M.Inst.C.E.

1908. (March 3.) "On the Physical Aspect of the Atomic Theory." By Professor J. LARMOR, Sec.R.S.

1909. (March 9.) "On the Influence of Moisture on Chemical Change in Gases." By Dr. H. BRERETON BAKER, F.R.S.

1910. (March 22.) "Recent Contributions to Theories regarding the Internal Structure of the Earth." By Sir THOMAS H. HOLLAND, K.C.I.E., D.Sc., F.R.S.

SPECIAL LECTURES.

1913. (March 4.) "The Plant and the Soil." By. A. D. HALL, M.A., F.R.S.

1914. (March 18.) "Crystalline Structure as revealed by X-rays." By Professor W. H. BRAGG, M.A., F.R.S.

1915. (May 4.) "The Place of Science in History." By Professor JULIUS MACLEOD, D.Sc.

DALTON LECTURE.

1931. (Mar. 17.) "Atoms and Electrons." By Sir Joseph J. Thomson, O.M., D.Sc., F.R.S.

JOULE MEMORIAL LECTURES.

1920. (Dec. 14.) "The Work and Discoveries of Joule." By Sir DUGALD CLERK, K.B.E., D.Sc., F.R.S.

1922. (Dec. 5.) "The Rise in Motive Power and the Work of Joule." By Sir CHARLES A. PARSONS, O.M., K.C.B., M.A., D.Sc., F.R.S.

1924. (Mar. 4.) "Thermodynamics in Physiology." By A. V. HILL, O.B.E., M.A., Sc.D., F.R.S.

1928. (Mar. 20.) "Sub-Atomic Energy." By Professor A. S EDDINGTON, M.A., D.Sc., LL.D., F.R.S.

1930. (Feb. 18.) "Science and Problems of the Times." By A. P. M. FLEMING, C.B.E., M.Sc., M.I.E.E.

1933. (Mar. 14.) "The Psychology of Musical Appreciation." By CHARLES S. MEYERS, C.B.E., F.R.S.

1934. (Feb. 27.) "The Expanding Universe as a Thermodynamic System." By Professor E. A. Milne, M.A., D.Sc., F.R.S.

WILDE MEMORIAL LECTURES.

1926. (Mar. 9.) "Brains of Apes and Men." By G. ELLIOT SMITH, M.A., M.D., F.R.S.

1927. (Mar. 22.) "Physiology of Life in the High Andes." By J. BARCROFT, C.B.E., F.R.S.

1929. (Mar. 19.) "The Nature and Origin of Human Speech." By Sir RICHARD PAGET, Bart.

1932. (Mar. 15.) "Man's Place in Nature as shown by Fossils." By Sir ARTHUR SMITH-WOODWARD, LL.D., F.R.S.

Awards of the Dalton Medal.

1898. EDWARD SCHUNCK, Ph.D., F.R.S.
1900. Sir HENRY E. ROSCOE, F.R.S.
1903. Prof. OSBORNE REYNOLDS, LL.D., F.R.S.
1919. PROF. Sir ERNEST RUTHERFORD, M.A., D.Sc., F.R.S.
1931. Sir JOSEPH J. THOMSON, O.M., D.Sc., F.R.S.

LIST OF PRESIDENTS OF THE SOCIETY.

Date of Election.	
1781.	PETER MAINWARING, M.D., JAMES MASSEY.
1782-1786.	JAMES MASSEY, THOMAS PERCIVAL, M.D., F.R.S.
1787-1789.	JAMES MASSEY.
1789-1804.	THOMAS PERCIVAL, M.D., F.R.S.
1805-1806.	Rev. GEORGE WALKER, F.R.S.
1807-1809.	THOMAS HENRY, F.R.S.
1809.	*JOHN HULL, M.D., F.L.S.
1809-1816.	THOMAS HENRY, F.R.S.
1816-1844.	JOHN DALTON, D.C.L., F.R.S.
1844-1847.	EDWARD HOLME, M.D., F.L.S.
1848-1850.	EATON HODGKINSON, F.R.S., F.G.S.
1851-1854.	JOHN MOORE, F.L.S.
1855-1859.	Sir WILLIAM FAIRBAIRN, Bart, LL.D., F.R.S.
1860-1861.	JAMES PRESCOTT JOULE, D.C.L., F.R.S.
1862-1863.	EDWARD WILLIAM BINNEY, F.R.S., F.G.S.
1864-1865.	ROBERT ANGUS SMITH, Ph.D., F.R.S.
1866-1867.	EDWARD SCHUNCK, Ph.D., F.R.S.
1868-1869.	JAMES PRESCOTT JOULE, D.C.L., F.R.S.
1870-1871.	EDWARD WILLIAM BINNEY, F.R.S., F.G.S.
1872-1873.	JAMES PRESCOTT JOULE, D.C.L., F.R.S.
1874-1875.	EDWARD SCHUNCK, Ph.D., F.R.S.
1876-1877.	EDWARD WILLIAM BINNEY, F.R.S., F.G.S.
1878-1879.	JAMES PRESCOTT JOULE, D.C.L., F.R.S.
1880-1881.	EDWARD WILLIAM BINNEY, F.R.S., F.G.S.
1882-1883.	Sir HENRY ENFIELD ROSCOE, D.C.L., F.R.S.
1884-1885.	WILLIAM CRAWFORD WILLIAMSON, LL.D., F.R.S.
1886.	ROBERT DUKINFIELD DARBISHIRE, B.A., F.G.S.
1887.	BALFOUR STEWART, LL.D., F.R.S.
1888-1889.	OSBORNE REYNOLDS, LL.D., F.R.S.
1890-1891.	EDWARD SCHUNCK, Ph.D., F.R.S.
1892-1893.	ARTHUR SCHUSTER, Ph.D., F.R.S.
1894-1896.	HENRY WILDE, D.C.L., F.R.S.

*Elected April 28th; resigned office May 5th.

Date of Election.	
1896.	EDWARD SCHUNCK, Ph.D., F.R.S.
1897-1899.	JAMES COSMO MELVILL, M.A., F.L.S.
1899-1901.	HORACE LAMB, M.A., F.R.S.
1901-1903.	CHARLES BAILEY, M.Sc., F.L.S.
1903-1905.	W. BOYD DAWKINS, M.A., D.Sc., F.R.S.
1905-1907.	Sir WILLIAM H. BAILEY, M.I.Mech.E.
1907-1909.	HAROLD BAILY DIXON, M.A., F.R.S.
1909-1911.	FRANCIS JONES, M.Sc., F.R.S.E.
1911-1913.	F. E. WEISS, D.Sc., F.L.S.
1913-1915.	FRANCIS NICHOLSON, F.Z.S.
1915-1917.	SYDNEY J. HICKSON, M.A., D.Sc., F.R.S.
1917-1919.	WILLIAM THOMSON, F.R.S.E., F.C.S., F.I.C.
1919.	G. ELLIOT SMITH, M.A., M.D., F.R.S.
1919-1921.	Sir HENRY A. MIERS, M.A. D.Sc., F.R.S.
1921-1923.	T. A. COWARD, M.Sc., F.Z.S., F.E.S.
1923-1925.	H. B. DIXON, C.B.E., M.A., Ph.D., M.Sc., F.R.S., F.C.S.
*1925.	Rev. A. L. CORTIE, S.J., D.Sc., F.R.A.S., F.Inst. P.
1925-1927	H. LEVINSTEIN, D.Sc., M.Sc., F.I.C.
1927-1929.	W. L. BRAGG, O.B.E., M.A., F.R.S.
1929-1931.	C. E. STROMEYER, O.B.E., M.Inst.C.E.
1931-1933.	B. MOUAT JONES, D.S.O., M.A.

LIST OF HONORARY MEMBERS OF THE SOCIETY.

Date of Election.	
Apr. 26th, 1892.	C. LIEBERMANN.
Apr. 17th, 1894.	J. W. L. GLAISHER.
do.	A. GOUY.
do.	SIDNEY VINES.
do.	EMIL WARBURG.
Apr. 30th, 1895.	SIR JOSEPH JOHN THOMSON, O.M.
Apr. 24th, 1900.	SIR J. ALFRED EWING.
do.	ANDREW RUSSELL FORSYTH.
do.	ROBERT RIDGEWAY.
May 13th, 1902.	SIR JOSEPH LARMOR.
do.	SIR OLIVER LODGE.
do.	HENRY FAIRFIELD OSBORN.
do.	DUKINFIELD HENRY SCOTT.
Apr. 28th, 1903.	FRANK WIGGLESWORTH CLARK.

*Died May 16th, 1925.

Date of Election.	
Apr. 5th, 1910	WALTHER NERNST.
Nov. 29th, 1921.	Sir HORACE LAMB.
do.	LORD RUTHERFORD, O.M.
do.	SIR ARTHUR SCHUSTER.
do.	G. ELLIOT SMITH.
Nov. 28th, 1922.	NIELS BOHR.
Apr. 13th, 1926.	SAMUEL ALEXANDER, O.M.
do.	ARNOLD SOMMERFELD.
Nov. 16th, 1926.	SIDNEY J. HICKSON.
do.	SIR HENRY A. MIERS.
May 13th, 1930.	F. E. WEISS.

LIST OF CORRESPONDING MEMBERS OF THE SOCIETY.

Date of Election.	
Feb. 3rd, 1920.	WILLIAM SALVADOR CURPHEY.
Nov. 1st, 1921.	MRS. C. W. PALMER.
Nov. 29th, 1923.	H. F. COWARD.
Apr. 1st, 1924.	GILBERT J. FOWLER.
Dec. 16th, 1924.	G. SENN.
Oct. 13th, 1925.	H. G. A. HICKLING.

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